Dynamics of Structures

final report for the research programme

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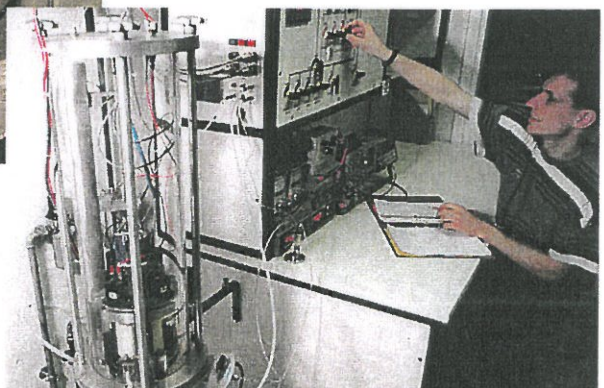
Final report for the research programme

DYNAMICS OF STRUCTURES

WAVE LOADS ON BREAKWATER

MODAL ANALYSIS OF MODEL BRIDGE



RESONANT COLUMN TEST ON SOIL

DEPARTMENT OF CIVIL ENGINEERING , AALBORG UNIVERSITY
DEPARTMENT OF BUILDING TECHNOLOGI AND STRUCTURAL ENGINEERING , AALBORG UNIVERSITY

SOHNGAARDSHOLMSVEJ 57, DK 9000 AALBORG , DENMARK

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MARCH 1998

FINAL REPORT

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1. Introduction

"Dynamics of Structures" was a research programme sponsored by the Danish Technical Research Council. The programme started in 1993 and continued until the end of 1997. It was a cooperative effort of the Department of Building Technology and Structural Engineering and the Department of Civil Engineering at Aalborg University and the Department of Structural Engineering at the Technical University of Denmark.

The purpose of the programme was to conduct research and provide research education and results relating to dynamic loads and response of civil engineering structures and foundations. Characterization and modelling of materials under time varying loads were also parts of the research programme. The research has developed and used both analytical, numerical and experimental methods.

The problem areas dealt with in the research programme were:

- Analysis of structures
- Wind and wave loads
- Soil mechanics
- System identification
- Damage detection
- Fatigue and crack propagation
- Man induced vibrations
- Experimental methods

The research programme was divided into 10 projects / problem areas:

A. BASIC THEORY

A.1 Mode shape and reduced base techniques
A.2 Wind and wave loads on structures
A.3 Dynamic response of structures with stochastic properties and excitation

B. EXPERIMENTAL TECHNIQUES

B.1 Damage detection in structures under random loading
B.2 Modal analysis based on the random decrement techniques
B.3 Fatigue and crack propagation

C. SELECTED DYNAMIC PROBLEMS

C.1 Behaviour of soil subjected to dynamic loads
C.2 Dynamic response of coarse granular materials to wave loads
C.3 Dynamics of sports stadiums
C.4 Dynamic measurements on the Frejlev mast

2. Original goal and plans for activities

A copy of the original application for the research programme is shown in appendix A. The applicant was professor, dr. techn. Steen Krenk at that time working at the Department of Building Technology and Structural Engineering at Aalborg University, see also chapter 8. Organization.

The total amount for the period 1993 - 1997 (5 years) was DDK 9,436,000, see also chapter 9. Economy.

In the original application the goal for the research programme is described in detail and the 10 projects / problem areas mentioned in chapter 1 in this report are also described in the original application. Project C.4 Dynamic measurements on the Frejlev mast was added a little later.

For each of the projects / problem areas a time schedule and a budget are presented in the original application, see appendix A, and a main budget is presented at page 4 in that paper.

The organization of the research programme is also mentioned, see page 3 of the application. (Unfortunately, professor Moust Jacobsen died and has never been active in the programme). A short CV for the senior participants in the programme is presented in annex A of the original application.

The main ideas of the research programme were the integration of theory and measurements and the integration of the disciplines of structural, soil and fluid mechanics as the 2 departments at Aalborg University are in close co-operation. Both are also partners in an experimental Centre for Dynamic Measurements (CDM), see appendix B. The centre was established in 1991 by a grant of 5,2 mill. DKK from the Danish Technical Research Council (STVF) and a grant from STVF of 2,5 mill. DKK in 1997.

3. Description of the programme 1993 - 1997

A description of the research programme is given in the 3 progress reports, see appendices G, H and I.

Furthermore the 10 projects in the programme are described in the report : "Description of the projects in the research programme DYNAMICS OF STRUCTURES", Department of Building Technology and Structural Engineering, Aalborg University, R9808, March 1998.

As described in chapter 8: Organization in this report Steen Krenk was leader of the research programme until summer 1995 where he got a leave from Aalborg University and worked at Lund University in Sweden. From summer 1995 Lars Pilegaard Hansen from Aalborg University has been leader of the programme. As described in the progress report 1995 , see appendix I, the programme was redefined in autumn 1995. Plans for 1996 are also described in the progress report from 1995. Except minor differences these plans have been followed until the end of the programme.

4. Obtained research results

Project A.1 Mode shape and reduced base techniques

In this project the development of efficient algorithms for large matrix systems with positive and sparse matrices has been obtained. A symmetry - preserving techniques has been developed for symmetric generalized indefinite and quadrtic eigenvalue problems which may open up for possibilities since it may require less computer power to handle e.g. the damped vibration.

The algorithms are implemented into MATLAB for which a toolbox FEMDYN for the dynamic finite element method has been developed. FEMDYN contains approximately 50 functions in form of element functions for global system matrices, algorithms for reduction methods, eigenvalue solutions and time step integrations for the forced vibrations. A FEMDYN manual is also presented and the functions are available as script files on a disc.

Project A.2 Wind and wave load s on structures

Vortex induced vibrations of structural elements

A double oscillator model for vortex-induced vibrations of structural elements based on exact power exchange between fluid and structure has been proposed. The model predicts two different modes of oscillation in the lock-in regime leading to hysteresis effects when the wind speed passes up and down through the lock-in interval. The effect of turbulence is to destabilize the mode with the highest amplification, thereby reducing the response amplitude, and for higher turbulence intensity to change the self-excited harmonic response to stochastic narrow-banded response with changing amplitude, closely resembling observed behaviour in experiments and full-scale structures.

Wind tunnel experiments have been carried out with a circular cylinder mounted on springs and tested in a wind tunnel. The vortex-induced vibrations and the pressure distribution around the central cylinder section were measured in low turbulent flow as well as in turbulent flows with different intensities and length scales.

Active control of monopile offshore platforms

An active technique for a monopile platform has been proposed and experimentally investigated.The technique is based on control of the boundary layer flow, and hence of the loading on the cylindre. The waveloading consists of a drag component and an inertial component. Only the drag component is under consideration. Normally, the drag coefficient is 0.6-0.9 for a circular cylinder. For a sharp edge body the drag coefficient can amount to 1.5-2.0. The cylinder will effectively acts as sharp edged body, if the boundary layer is forced to separate before the naturally separation points. The separation of the boundary layers will be insured by blowing air from inside the cylinder whenever appropriate.

The versability of the principle has been demonstrated by a series of initial tests, in stationary flow and regular waveloadings. During the final tests with an optimized test setup were performed, showing a reduction of the vibration level of approximately 50%.

Project A.3 Dynamic response of structures with stochastic properties and excitation

Response and damage assessment of reinforced concrete frames subject yo earthquakes

An algoritm for localization of damage in instrumented structures has been developed and verified by model testing on a scale 1:5 reinforced concrete frame. In Turkey and other middle east countries it is a custom only to build the lower part of a building at first and then leave the upper storeys until later, when the need and the available money turns up. This creates a weakening in the mid of the structure, which turns out to accumulate damage. The same effect of accumulation of damage in the midst of structures was observed in the 1996 Kobe earthquake, where the effect was caused by a discontinous change of the strength and stiffness of the outer columns of the building. The applicability of the devised algoritms in predicting such damage accumulations in the midst of a structure was also demonstrated by laboratory tests.

Influence of surface irregularities and vehicle uncertainties on the dynamic response of shortspan highway bridges

A common problem in bridge engineering practice in these years is the upgrading of minor highway bridges (span=5-20 m) to carry heavier loads partly due to a tendency of heavier trucks moving at larger speeds, and partly because the authorities want to permit transportation of heavier goods at a larger part of the road net. For the minor highway bridges the critical design scenario occurs at the simultaneous passage of two heavy trucks, which according to the present Danish regulations are taken as a 50t and a heavier 100-150 t vehicle. For both these vehicles the dynamic amplification factor is taken as 1.25, which is generally considered too conservative among bridge engineers.

In the project some investigations on the probability distribution of the dynamic amplification factor is presented, based on Monte Carlo simulation studies. Numerical 3D-models have been formulated for the vehicles with parameters calibrated to a 50t Scania and a 100t Goldhofer truck. A characteristic highway bridge has been selected, and a numerical FEM-model has been formulated with due consideration to the dominating quasi-static response of minor highway bridges. Overtaking scenarios, where the trucks cross the crests and troughs of the whell tracking, have been considered as well. The influence of the uncertainty of the parameters of the suspension system and the vehicle velocities has been investigated.

The overall conclusion from this part of the investigation is that the most important impact on magnitude of the dynamic amplification factor stems from short waved bumps, whereas the attrition of the surface dressing is less important.The results of the project have been met with interest among bridge engineers, and have initiated discussion on the reduction of the safety factors for reinforcement projects.

Project B.1: Damage detection of structures under random loading

The most important results have been obtained in the system identification part of the project. A full covariance equivalent vector ARMA model have been formulated with direct reference to the mechanical system using PEM methods, i.e. the model is able of containing exactly the right information both physically and statistically assuming any linear system loaded by Gaussian processes, and modal parameter are identified using regression directly on the time series. The technique allows for estimation of the covariance matrix of all estimated parameters, and it is implemented in a user friendly toolbox under MATLAB. As a results of this work, a clear connection between the physical model formulated in continuos time and the vector ARMA model formulated in discrete time has been established.

In the damage detection part of the project, a method for filtering out environmental influence on the modal parameters has been formulated and testing on real data. System identification using the vector ARMA model has been performed on a wind loaded truss pylon structure with a slowly growing crack. It has been shown, that a crack covering the half of the cross section in a single brace in the truss structure can be identified under changing environmental conditions using the techniques developed in this project.

Project B.2 Modal analysis based on the random decrement techniques

In this project the Random Decrement (RD) techniques has been fully developed and a large set of different estimation procedures has been implemented and tested on real data. The theoretical basis of the RD technique has been significantly improved concerning construction of arbitrary triggering conditions, choice of triggering condition and variance on the estimated RD functions. Sources of bias has been identified and illustrated, and new ideas like triggering on several signals at the same time (vector triggering conditions) has been theoretically developed, tested and optimized for practical applications.

A fully developed two stage modal analysis technique based on the RD technique for estimation of free response functions from the ambient responses of civil engineering structures and on the Ibrahim Time Domain and the Polyreference Time Domain method for extraction of the modal parameters, has been implemented in a user friendly toolbox under MATLAB. The software has been used for analysis of several highway bridges. Further, an eight-channel, low-noise measurement system has been developed for ambient response measurements. The measurement system has been used on a highway bridge.

Project B.3 Fatigue and crack propagation

The project deals with a newly developed crack growth model based on an energy criterion and this model is able to predict crack propagation in ductile as well as brittle materials. The crack propagition formula is a first order differential equation. The energy changes required may be determined using simple linear elastic finite element methods. The non-linearity is taken into account using Irwins crack length correction.

The theory is compared with experimental results with three point bending tests on concrete beams. It is shown that the theory is able to prodict size effects.

Futhermore the theory is compared with tests on fatigue loaded high strength steel and aluminium. It is shown that the critical stress intensity factor is not a constant but clearly depends on the stress intensity factor.

The theory has also been compared with test results on welded steel connections.

Project C.1 Behaviour of soil subjected to dynamic loads

Many geotechnical problems involve design of dynamically loaded foundations. The design criterion for dynamically loaded foundations is often described in terms of limiting values for the displacements. The displacements in the soil are normally very small when dealing with dynamically loaded foundations, and hence it is necessary to know the deformation properties for the soil at very low strain level. The main topic of the project was to increase the knowledge of the behaviour of Danish soils at small strain levels and to extent the laboratory facilities to deal with testing at small strains. The soil behaviour at very small strain levels is non-linear, and the most common testing technique for this situation is the resonant column technique. One of the aims of this project was to install, check, get familiar with and perform tests on different kinds of Danish soils in a new Drnevich Longitudinal-Torsional Resonant Column apparatus placed at the Soil Mechanics Laboratory at Aalborg University. Another, but quite new technique for small strain testing to determine the maximum shear modulus, G_{max}, is the bender element technique, and as part of the project this technique has also been introduced in the laboratory.

The project has led to a better understanding of the interplay between the existing test set -ups and the results they produce. Based on the results obtained improved numerical interpretation tools have been developed and the importance of the shape of the driving signals for measurements using bender elements has been demonstrated. It is anticipated that it will be possible to automate the interpretation process.

Project C.2 Dynamic response of coarse granular materials to wave loads

Part 1

The Single Hardening Model was introduced and investigated with the purpose of evaluating its capability of predicting the behaviour of frictional materials. The database, resulting from the work in project C.2.2, has been used for the calibration of the model. Besides providing a solid basis for the parameter study, the triaxial tests serve to elucidate the general behaviour of sand.

Among other things, the aim of this work has been to investigate the applicability of the Single Hardening Model for solving geotechnical problems of a more complex nature. In this task a caisson breakwater structure, which has been tested in the centrifuge at Delft Geotechnics, is modelled in ABAQUS by means of the verified material model subroutine containing the Single Hardening Model. The response of the caisson is investigated under drained as well as undrained conditions. The results from the numerical analysis are compared to results obtained from the centrifuge test. Furthermore, an analytical bearing capacity analysis in the shape of an upper bound solution is put forward as a reference for the numerically obtained horizontal bearing capacity. Finally, reference numerical calculations based on the simpler Drucker-Prager Model are brought in for comparison. The performed analysis with the Single Hardening Model and have these analysis are compared, with analytical and the centrifuge test.

Part 2

The soil beneath vertical breakwaters is subjected to a combination of forces induced by the waves. This forces can be characterize as, static load due to the submerged weight of the structure, quasi-static forces induced by cyclic wave loading and wave impact induced by breaking waves. Therefore, the main objective for this sub project has been to establish a data base which have served to investigate/determine verus relationships and soil response subjected to this kinds loading. The data base contains static, cyclic and dynamic triaxial tests, performed on gravel and sand with various grain size distribution, relative densities, and consolidation stresses.
The key to explained and predict the soil response beneath a vertical breakwater is to understand the role of the volume changes and to be able to model these correct. The tests in tests in the data base has shown, that the volume changes in soil subjected to static and dynamic loading is controlled by the characteristic line. The Experiments in the data base, have been performed to study the factors that influence the location of the characteristic line in drained and undrained tests for various types of sand and various types of loading. These factors include the relative density, the minor principal stress, the intermediate principal stress, the influence of stress path and the effect of nonhomogeneous and localized strains. The relation of the characteristic line to other features of soil behavior, cyclic and dynamic, are explained and illustrated with these experimental data.

Part 3

The objective of the project on hydraulic response of caisson breakwaters in multidirectional breaking and non-breaking waves was to assess the effects of wave obliquity and multidirectionality on the wave induced loading and overtopping on caisson breakwaters situated in breaking seas. Regarding the wave forces only mimor differences between breaking and non-breaking waves in deep water were observed, and it was found that the prediction formula of Goda also seems to apply for multidirectionallly breaking waves at deep water . The study on wave overtopping showed that the 3D wave overtopping formula suggested by Franco, predicts the wave overtopping reasonable well for both non-breaking and breaking waves in deep water.

Project C.3 Dynamics of sports stadiums

In the design of sports stadiums the dynamic effects from spectator movement constitutes an important part. In this project the main focus has been on the development of spectator load models that give a realistic representation of the vertical force exerted by the individual spectator on the structure when performing repetitive motion.

Analytical expressions of force amplitude spectra for both deterministic and stochastic pulse trains have been found for a variety of different impulse shapes.

Experimental investigations have been performed for vertical motions at different motion frequencies in order to determine the relevant motion parameters: the experimental load spectra, the influence of the structural eigenfrequency and the structural stiffness.

These investigations show that it is possible to use impulse based models for assesment of the vertical force exerted by repetitive vertical human motion.

Project C.4 Dynamic measurements on the Frejlev mast

The aim of this project was to make full-scale measurements on the Frejlev-mast which is a 200 meter high guyed steel mast located 10 km. from Aalborg. The goal was to investigate the uncertainties of the estimated cable forces from vibration measurements. In order to establish the relationship between frequencies and cable forces different models of the dynamic response of a cable have been investigated. Firstly, the cable forces have been estimated by a simple relationship between estimated natural frequencies and the cable forces in a linear cable. Secondly, the cable forces were estimated using a model taking into account the measured excitation of the support at the location where the cable was attached to the mast. Before these approaches for estimation of the cable forces were used on the measured data from the Frejlev mast, simulation studies were performed. The results obtained from the simulation studies showed that it was possible to obtain reliable estimates for cable forces based on measured natural frequencies. Further, by comparing the estimated cable forces obtained from the measured data with the assumed cable forces in the cables, it was concluded that reliable cable forces can be estimated based on measured natural frequencies.

5. Education of researchers

A major part of the research programme comprised Ph.D. projects as described briefly in the following.

The projects are described in more detail in the report "Description of the projects in the research programme DYNAMICS OF STRUCTURES", Department of Building Technology and Structural Engineering, Aalborg University, R9808, March 1998, in the following abbreviated "Dynamics of Structures".

A.1 Mode shape and reduced base techniques

Ph.D. student: Steffen Vissing
Supervisor: Professor, dr. techn. Steen Krenk
Period: 1.1.93 - 31.12 95
Ph.D. thesis: *A generalized Lanczos - QR technique*, pp 149, Department of Building Technology and Structural Engineering, Aalborg University, December 1995.

For more information about this project, see "Dynamics of Structures"

A.3 Dynamic response of structures with stochastic properties and excitation

Ph.D. student: Poul S. Skjærbæk

Supervisor:	Reading professor, dr. techn. Søren R. K. Nielsen
Period:	1.9.94 - 31.5.97
Ph.D. thesis:	*Response and damage assessment of reinforced concrete frames subjected to earthquakes,* pp 258, Department of Building Technology and Structural Engineering, Aalborg University, June 1997.

This project has been supported by Aalborg University (Ph.D. salary) and the research programme.

For more information about this project, see "Dynamics of Structures"

B.1 Damage detection in structures under random loading

Ph.D. student:	Palle Andersen
Supervisor:	Associate professor, lic. techn. Rune Brincker Associate professor, Ph.D. Poul Henning Kirkegaard
Period:	1.9.93 - 30.4 97
Ph.D. thesis:	*Identification of civil engineering structures using vector ARMA models,* pp 244, Department of Building Technology and Structural Engineering, Aalborg University, May 1997.

For more information about this project, see the paper with the same title in "Dynamics of Structures"

B.2 Modal analysis based on random decrement signatures

Ph.D. student:	John C. Asmussen
Supervisors:	Associate professor, lic. techn. Rune Brincker Professor, Ph.D. Sam Ibrahim
Period:	1.9.94 - 31.8 97
Ph.D. thesis:	*Modal analysis based on the random decrement technique - Application to civil engineering structures,* pp 215, Department of Building Technology and Structural Engineering, Aalborg University, August 1997.

For more information about this project, see the paper with the same title in "Dynamics of Structures"

B.3 Fatigue and crack propagation

Ph.D. student:	Thomas Cornelius Hansen
Supervisor:	Professor, dr. techn. Mogens Peter Nielsen
Period:	1.1.93 - 31.12 95
Ph.D. thesis:	The thesis consists of 4 parts:

Fatigue and crack propagation, BKM, Technical University of Denmark, Report no 316, T.C.Hansen, 1994

Fatigue in high strengths steel, BKM, Technical University of Denmark, Report no 9, T.C.Hansen, 1996

Fatigue in welded connections, BKM, Technical University of Denmark, Report no 10, T.C.Hansen, 1996

Fracture and crack growth in concrete, BKM, Technical University of Denmark, Report no 11, T.C.Hansen and D.H.Olsen, 1996

For more information about this project, see the paper with the same title in "Dynamics of Structures"

C.1 Behaviour of soil subjected to dynamic loads

Ph.D. student:	Lars Bødker
Supervisors:	Associate Professor, Ph.D. Lars Bo Ibsen
	Professor, Ph.D. Jørgen S. Steenfelt
Period:	1.7.94 - 31.12 97
Ph.D. thesis:	*Determination of elastic parameters for soil subjected to dynamic loadings,* Department of Civil Engineering, Aalborg University, 1998.

For more information about this project, see the paper with the same title in "Dynamics of Structures"

It can be concluded that an essential part of the research programme is the 6 Ph.D. projects. 5 of the projects have been successfully defended and the last one will be defended in 1998.

6. Co-operation - National and International

In the research programme there has been a great deal of co-operation with other research institutes, consulting firms, industrial companies and persons on a more individual basis.

Some of the contacts are described in the progress reports, see appendices G, H and I, and in the report "Description of the projects in the research programme Dynamics of Structures". This chapter only provides a short description of the co-operation both nationally and internationally .

In the ***project A.1*** co-operation with the Division of Mechanics, Lund University has been established. Tekn. Dr. Håkan Carlsen and Tekn. Dr. Matti Ristinmaa visited Aalborg University in 1993. Some lecture notes have been written and used at Lund University and Aalborg University. A contact was also established with the Technical University of Delft, The Netherlands, as Hilda van der Veen visited Aalborg University in 1995. The Ph.D. student

Steffen Vissing has also spent some time in Lund and Delft.

In the ***project A.2*** there has been several contacts. A project on wind induced vibrations has been conducted in co-operation with students from the Technical University of Denmark and the consulting firm Svend Ole Hansen Aps. Another project on simulation of turbulent natural wind was a co-operation with Jacob Mann at Risø Research Centre. The extreme winds in the eastern part of Denmark have been estimated from available data from the Øresund Bridge project. Michael Kleiser from Technische Universität Wien visited Aalborg University financed by the EU Human Mobility programme and worked on vortex-induced vibrations. There has also been a close contact to the committee writing a new Danish design code for wind loads and to another framework programme "Safety and Reliability of Structures" also sponsored by the Danish Technical Research Council. A study on the effect of stochastic fluctuations of the wind speed on the resonant amplitude has been conducted in co-operation with Svend Ole Hansen Aps. Vinay Gupta, India Institute of Technology, Kundar has also visited the research programme and has given a lecture on stochastic vibration.

In a project entitled "Active Vibration Control of Monopile Platforms" a co-operation with the consulting firm Rambøll, Esbjerg, has been established.

In the ***project A.3*** Søren R.K. Nielsen has been in close co-operation with researchers from Princeton University, USA, on the work on the formulation of analytical models for the dynamic response of structures with random parameters subjected to stochastic dynamic excitations. In a project on identifying eigenfrequencies using discrete wavelet analysis Ray Micaletti from Princeton University, USA, visited Aalborg University for 3 months financed by the research programme. The Ph.D. student Poul Skjærbæk visited Princeton University, USA for half a year in the beginning of 1996 and together with the supervisor, Søren R.K. Nielsen, many contacts were established. Chris Mullen, Missisippi State University has also visited the research programme and has given a lecture on earthquake engineering.

In 1995/96 a new project entitled "Dynamic Amplification Factors in Relation to Traffic Loads at Reinforcement Projects on Minor Highway Bridges" was initiated in co-operation with the consulting firm Rambøll, Copenhagen.

In the ***project B.1*** several contacts have been established.Together with the consulting firm INTEVEP A.S in Venezuela data from the dynamic response of an offshore platform have been analysed using an ARMA model. Also data from the Norwegian Gullfaks offshore platform have been analysed in co-operation with Ivar Langen from Høgskolesenteret i Rogaland, Norway. Another co-operation was with Anders Rytter at the Applied Mechanics Unit at the European Laboratory for Structural Assessment in Ispra, Italy. In this research damage assessment technique was applied on a reinforced concrete structure. Anders Rytter has also been involved in another project on dynamic analysis of cracked steel beams together with Marek Krawczuk from the Polish Academy of Sciences. A working group has been established with the subgroup "Monitoring and Evaluation" of EG-SEA-AI (European Group for Structural Engineering Applications of Artificial Intelligence). The Ph. D. student Palle Andersen spent 4 months at the Department of Civil Engineering at the Aristotle University of Thessaloniki, Greece and worked with professor G.C.Manos. During this visit Palle Andersen was attached to the EU founded EURO SEIS Test programme. Professor Piombo from Torino University, Italy has visited Aalborg University as well as professor Sam Ibrahim from Old Dominion University, USA.

In the ***project B.2*** the Ph.D student John Asmussen has spent 4 months at the Department of Civil Engineering at the Aristotle University of Thessaloniki, Greece with professor G.C.Manos. During this visit John Asmussen was attached to the EU founded EURO SEIS Test programme. Professor Sam Ibrahim, Old Dominion University, USA has spent several months at Aalborg University and has been co-supervisor for the project. Rune Brincker and John Asmussen also visited Professor Sam Ibrahim at Old Dominion University. In co-operation with Professor Ventura from University of British Columbia the Exchange of data and analysis of ambient measurement of bridges have been performed. Together with the consulting firm Rambøll and the Danish Road Directorate the initial phase of a research project concerning damage detection of structures has been carried out.

In the ***project B.3*** the Ph.D. student, Thomas Cornelius Hansen, has been on a 3 month stay at professor B. Karihaloo, University of Sidney, Australia. Another co-operation was to the Federal Institute of Technology with F.H. Wittmann. Also senior researcher Hans Hanrik Bache at CtO at Aalborg Portland, Denmark has been involved in the project.

In the ***project C.1*** the Ph.D. student Lars Bødker has visited the Norwegian Geotechnical Institute in Oslo for 4 months. Beyond the actual research programme the project also entails a close co-operation with the LITASIS project which is an international and interdisciplinary project dealing with field and laboratory measurements of the dynamic properties of soil. One of the supervisors in the project has spent several months at John Hopkins University, USA and several contacts have been established during this stay.

The international contacts and cooperation have been extensive in ***project C.2***. This is due to the strong connection to two large European projects under the 2nd and 3rd Research Programs of the European Union on Marine and Science Technology (MAST). In both of these projects there was a close co-operation among 23 partners from 8 European countries.

The strongest connection has been establish between Leichtweiss-institut der Technichen Universität Braunschweig, (DE), Delft Geotechnich (NL) and The Norwegian Geotechnical Institute (NO). At these partners 7 students have done parts of there master projects at these institutions. Kim P. Jacobsen has spent 5 month at the Norwegian Geotechnical Institute in connections with his Ph.D project. From Slovakia Juraj Blanar has joined the project and has been involved in the experimental work. The research has continued under MAST III.

In the ***project C.3*** there has been contacts to the Danish Athletics Union working on safety for Danish sports stadiums. Contacts have also been established to Anatomic Institute, University of Copenhagen. In connection with the project a visit has been arranged to Dr. Sven Ohlsson, Unit for Dynamics in Design, Chalmers University of Technology, Sweden for changing information on man-induced dynamic loading. Also B.R. Ellis at the Building Research Establishment, Garston, United Kingdom has been involved in the project.

In the ***project C.4*** the consulting firm Rambøll, Copenhagen has been contacted in connection with the measurements of the Frejlev Mast.

7. Communication of results

The results from the research programme have been communicated in many different ways.

First of all the co-workers in the research programme have published

- Ph.D. theses
- Papers in international journals
- Conference papers
- Reports in research series at the 2 departments
- Test reports on laboratory testing
- Papers for the seminars (workshops) held in connection with the research programme

Some of the publications are avaiblable via the internet.

A complete list of the publications prepared and written in the research programme is given at the end of this report.

Secondly there has been 3 seminars (workshops) in connection with the research programme.

The first seminar (workshop) was held at Aalborg University, September 14 - 15, 1994 and the programme, a list of participants and a copy of the first page of the papers presented at the seminar are shown in appendix C.
The papers presented at the seminar are collected as reference 1 in the end of the publication list at the end of this report.

The second seminar (workshop) was held at Aalborg University, November 13 - 14, 1996 and the programme, a list of participants and a table of contents for the papers presented at the seminar are shown in appendix D.
The papers presented at the seminar are collected as reference 2 in the end of the publication list at the end of this report.

The third seminar (Information day) was held at Aalborg University, November 26, 1997 as a local arrangement (in Danish) for the co-workers at the 2 departments. The programme for this seminar is shown in appendix E.

Thirdly an information pamphlet has been produced and distributed to many research institutions, consulting firms and companies. This information pamphlet is shown in appendix F.

Finally information about the research programme has also been disseminated through personal contacts to all the research institutions, consulting firms and companies mentioned in chapter 6. Most of the Ph.D. students have worked at another research institution in a foreign country during an extended period and many international contacts are created through this activity.

8. Organization

At the start of the research programme in 1995 Steen Krenk was the leader of the programme and a programme committee was formed consisting of the leader of the programme, 2 external members and 1 member from the Department of Civil Engineering, Aalborg University, the Department of Building Technology and Structural Engineering, Aalborg University and the Department of Structural Engineering, Technical University of Denmark.

The 2 external members of the programme committee have been:

Svend Ole Hansen, Svend Ole Hansen Aps , Copenhagen (chairman)
Knut H. Andersen, Norwegian Geotechnical Institute, Oslo, Norway

There have been meetings in the programme committee 1-2 times per year. A procedure for the programme committee (in Danish) is given in appendix J.

An evaluation from the 2 external members of the programme committee is given in appendix K.

Besides the meetings in the programme committee there have been 5 - 10 meetings per year for all the participants in the research programme. During these meetings the progress of the projects has been discussed as well as other subjects of interest for the research programme.

In the summer of 1995 Steen Krenk obtained a leave of absence from Aalborg University to work at Lund University in Sweden. From the summer of 1995 and until the end of 1997, Lars Pilegaard Hansen has been the leader of the programme.

In 1995 the Danish Technical Research Council carried out an evaluation of research programmes financed by the council. This programme was evaluated by professor David Muir Wood, Department of Civil Engineering, The University of Glasgow, Scotland and professor Bengt Åkesson, Division of Solid Mechanics, Chalmers University of Technology, Göteborg, Sweden. The report from this evaluation is given in "Midtvejsevaluering- Ingeniørvidenskabelige centre og rammeprogrammer- Statens Teknisk-Videnskabelige Forskningsråd - September 1995" and the evaluation for this programme is shown in appendix L.

9. Economy

The complete account is given in a seperate document to the Danish Technical Research Council and only an overview is given in table 9.1.

Table 9.1 Expenses in DKK (1 US$ ~ 6,90 DKK, March 1998)

Project	Salary	Tax.contrib.	Equipment	Various	Overhead	Total
Common	249.588,00		21.591,50	180.489,14	61.226,93	512.895,57
A.1	576.521,00	247.600,00	142.145,60	69.320,76	80.987,44	1.116.574,80
A.2	0,00	0,00	17.142,00	181.466,37	34.079,42	232.687,79
A.3	208.592,10	0,00	157.496,64	192.733,03	88.390,62	647.212,39
B.1	739.384,51	309.166,00	92.460,94	98.488,29	189.775,04	1.429.274,78
B.2	523.687,40	311.399,00	45.734,40	189.852,17	211.197,68	1.281.870,65
B.3	597.367,11	334.683,00	6.250,00	86.829,26	78.346,63	1.103.476,00
C.1	681.576,42	308.100,00	232.553,43	120.243,93	221.417,51	1.563.891,29
C.2	899.185,47	0,00	217.927,91	391.625,01	216.819,25	1.725.557,64
C.3	0,00	0,00	13.072,60	249.542,79	50.239,03	312.854,42
C.4	199.942,32	0,00	17.561,75	4.937,10	44.488,24	266.929,41
Total	4.675.844,33	1.510.948,00	963.936,77	1.765.527,85	1.276.967,79	10.193.224,74

Please observe the following comments given to the table:

1. Tax. contrib. in the first row means taxameter contribution and is a "tax" paid to the university (doctoral school and departments) in connection with each Ph.D. project covering the educational expenses for the Ph.D. student.
2. Overhead in the first row means "tax" to the university from external programmes for example programmes financed by the Danish Technical Research Council.
3. The row Common covers common expenses for the programme. Some of these expenses are expenses in the 10 projects and the amount 180,489.14 covers for example visits of some of the guests.
4. The amount 142,145.60 in the project A.1 under equipment is for the most part purchase of a workstation.
5. The amount 181,466.37 in project A.2 under various includes 88,357.60 for external consultant salary.
6. The Ph.D. expenses i project A.3 are paid by Aalborg University.
7. The amount 157,496.64 under equipment in project A.3 includes purchase of a workstation for 120,892.76
8. The amount for salary in project B.1 is salary for the Ph.D. student and a research

assistant (230,443.00)

9. The amount for salary in project B.2 is salary for the Ph.D. student and a research assistant (109,262.00)
10. The amount 391,625.01 in project C.2 includes 81,002.16 for external consultant salary.
11. The amount 249,542.79 in project C.3 includes 224,634.00 for external consultant salary.
12. The amount for salary in project C.4 is salary for research associate professor.

The distribution of the 5 different columns in table 9.1 is shown in figure 9.1.

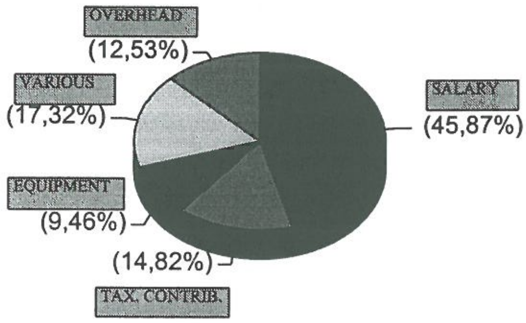

Figure 9.1 Distribution of expenses

The distribution for the different projects is shown in figure 9.2

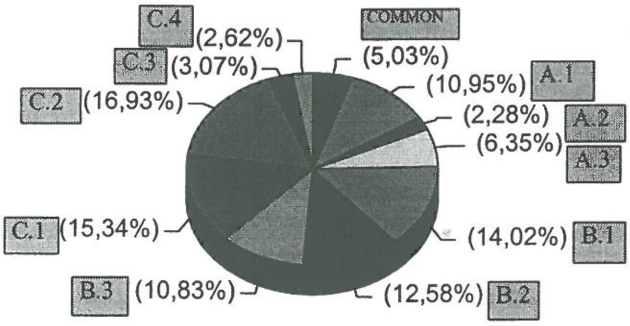

Figure 9.2 Distribution of expenses for the 10 projects and common

As mentioned in the original application, see appendix A, a considerable contribution has also been given by the 2 departments at Aalborg University. This contribution covers both scientific and technical / administrative personnel. The amount can be estimated to approximately 3 mill. DKK. The Centre for Dynamic Measurements has supplied the research programme with equipment and the expenses for equipment has thus been relatively small.

As mentioned in the description of the project C.2 there has been a close co-operation with the MAST II project . Financial support from the Danish Technical Research Council has been given to a project (grant No. 9502738) working in co-operation with project A.3.

10. Final remarks

The main conclusion is that the research programme has met most of its objectives. In all the Ph.D. projects the activity has been very high. The results in the projects have been (or will soon be) published internationally in a large number of papers or have been presented at international conferences.

The research programme has opened many relations to Danish and foreign institutes and consulting engineering companies which will be very usefull for the 2 departments in the future.

The research programme has thus provided more knowledge and data to design dynamically sensitive structures in a more reliable and economic way.

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Aalborg, March 25, 1998.

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2. Dynamics of Structures: Workshop on Dynamic Loads and Response of Structures and Soil Dynamics, Aalborg University, Denmark, November 13-14, 1996.

APPENDIX A

Original application

SKEMA 1

Dato:

Forskningsrådene
The Danish Research Councils

H.C. Andersens Boulevard 40
DK-1553 København V
Danmark
Fax +45 3332 3501
Tel +45 3311 4300

Ansøgning om støtte til projekter

Fra Statens teknisk- videnskabelige **Forskningsråd**

Læs vejledningen og informationsfolderen, før skemaet udfyldes

1	Ansøgerens navn (den over for forskningsrådet ansvarlige)	Steen Krenk
	CPR-nr. for ansøger	030149-0321
2	Stilling og uddannelse	Professor, Dr.techn.
3	Arbejdsplads Adresse og telefon	Instituttet for Bygningsteknik, Aalborg Universitetscenter Sohngårdsholmsvej 57, 9000 Aalborg / 98 15 85 22
	Privatadresse og telefon	Absalonsgade 37 st.tv., 9000 Aalborg / 98 11 18 33
	Sted for projektets udførelse Adresse og telefon	Aalborg Universitetscenter Sohngårdsholmsvej 57, 9000 Aalborg / 98 15 85 22
4	Projektets titel (højst 20 ord)	Konstruktioners Dynamiske Forhold
5	Ansøgt beløb for det **1. år** (excl. moms)	1.392.000 kr. — Beløbet ønskes anvendt i perioden:
6	Projektets forventede samlede varighed	Start: 1.1.1993 — Slut: 31.12.1997
	Projektets forventede **fremtidige** behov for støtte fra forskningsrådet ud over det i punkt 5 anførte beløb	2. år: 2.117.000 3. år: 2.482.000 4. år: 1.961.000 5. år: 1.484.000
7	Er det under punkt 5 anførte beløb søgt andet steds (helt eller delvis) Hvorfra og med hvilke beløb?	Sæt kryds: er ikke søgt _X_ søges ____
8	Søges der om midler fra et særprogram angives dette ved navn	STVF rammeprogrammer 1993-97: nr. 13, Konstruktioners dynamiske forhold
9	Hasteansøgning	Sæt kryds: ____ Begrundelse vedlægges

Forbeholdt sekretariatet:

Modtaget	Fagkode
	Prioritetskode
	Behandlingskode
	Forbehandling

10 Øvrige medarbejdere i projektgruppen (navn, stilling, arbejdsadresse)

Rune Brincker, Lektor, Ph.D.
Lars Pilegaard Hansen, Docent, Ph.D.
Søren R. K. Nielsen, Docent, Ph.D.
Instituttet for Bygningsteknik, Aalborg Universitetscenter, Sohngårdsholmsvej 57, 9000 Aalborg

Hans F. Burcharth, Ingeniørdocent
H. Moust Jacobsen, Professor, Ph.D.
Inst. for Vand, Jord og Miljøteknik, Aalborg Universitetscenter, Sohngårdsholmsv. 57. 9000 Aalborg

Mogens Peter Nielsen, Professor, dr.techn.
Afd. for Bærende Konstruktioner, Danmarks Tekniske Højskole, Bygning 118, 2800 Lyngby

11 Kort projektbeskrivelse, der er egnet til offentliggørelse

Konstruktioners dynamiske forhold omfatter situationer hvor variationen med tiden er af betydning for konstruktionens opførsel. Tidsafhængigheden kan omfatte belastningen og responset, men kan også give sig udslag i gradvis beskadigelse af konstruktionen, som i forbindelse med udmattelse af metaller. I mange tilfælde afhænger en konstruktions dynamiske opførsel af konstruktionens vekselvirkning med omgivelserne som f.eks. vand, luft eller jord. Dette kan ske enten ved at belastningerne påføres via omgivelserne eller ved at disse ændrer konstruktionens dynamiske egenskaber. Dette forskningsprogram omfatter derfor konstruktioner, deres vekselvirkning med omgivelserne, samt undersøgelser af skadevirkning som f.eks. udmattelse. Der er tale om en integreret indsats omfattende feltmålinger, forsøg, modeldannelse og numeriske analysemetoder. Blandt de emner der behandles er: beregningsmodeller for vekselvirkning mellem konstruktioner og væsker samt for konstruktioner med stærkt varierende egenskaber, eksperimentelle teknikker til at identificere skader i konstruktioner, modstandsevnen af konstruktioner funderet i bølgeslagszonen, samt bygningers påvirkning ved dynamiske forstyrrelser som f.eks. pæleramning.

12 Detaljeret budget for det ansøgte beløb for 1. projektår og bemærkninger vedr. følgende år

Detaljerede budgetter indeholdt i delprojekterne

13 Totalbudget for projektet.
Opstilles efter reglerne om indtægtsgivende forskningsvirksomhed

Budgetpost	Fra forskningsråd		Fra arbejdssted		Søges/bevilget fra anden side	
	antal månedsværk	kr.	antal månedsværk	kr.	antal månedsværk	kr.
1. år						
VIP-løn		842.000	17	510.000		
TAP-løn		125.000	2	30.000		
Apparatur over 40.000 kr.		110.000		★)		
Driftsudgifter		274.000				
Adm. bidrag/overhead		41.000				
I alt		1.392.00		540.000		
2. år				★★)		
VIP-løn		1.485.000	24	720.000		
TAP-løn		185.000	4	60.000		
Apparatur over 40.000 kr.				★)		
Driftsudgifter		385.000				
Adm. bidrag/overhead		62.000				
I alt		2.117.000		780.000		
3. år				★★)		
VIP-løn		1.940.000	36	1.080.000		
TAP-løn		175.000	4	60.000		
Apparatur over 40.000 kr.				★)		
Driftsudgifter		295.000		—		
Adm. bidrag/overhead		72.000				
I alt		2.482.000		1.140.000		
4. år				★★)		
VIP-løn		1.443.000	20	800.000		
TAP-løn		125.000	2	30.000		
Apparatur over 40.000 kr.		120.000		★)		
Driftsudgifter		216.000				
Adm. bidrag/overhead		57.000				
I alt		1.961.000		630.000		
5. år						
VIP-løn		325.000	4	120.000		
TAP-løn		95.000				
Apparatur over 40.000 kr.				★)		
Driftsudgifter		50.000				
Adm. bidrag/overhead		14.000				
I alt		484.000		120.000		
I alt for de 5 år		8.436.000★★★)				

★) Instrumentcenter for Dynamik

★★) AUC Ph.D.

★★★) Forhøjes skønsmæssigt til 9.436.000 som nævnt i bilag 1.

Stempel og underskrift fra institutionen

14 Supplerende oplysninger

15 Har De inden for de sidste 3 år fået bevilget støtte fra et forskningsråd til dette eller andre projekter?

Samme projekt Ja	Samme projekt Nej	År	J.nr.	Bevilget beløb	Projekttitel
	x	1990	16-4157.B	174.300	Stabilitet af tyndvæggede usymmetriske stålbjælker
		1991	16-4157-2	284.589	- do -
		1991	16-4157-3	102.113	- do -

16 Bilagsfortegnelse:

Bilag 1: DYNAMICS OF STRUCTURES
Bilag 2: Annex A: Resume of Senior Participants

Underskrift

DYNAMICS OF STRUCTURES

STVF-rammeprogram nr. 13: Konstruktioners dynamiske forhold

The subject area 'Dynamics of Structures' covers phenomena related to time dependent loading, response and possible deterioration of structures, e.g. in the form of fatigue. In many instances the dynamic behavior depends on the interaction of the structure with soil, water or air. The soil, water and air may generate the loading process or combine with the structure to modify response. Thus a comprehensive research effort within the area of 'Dynamics of Structures' must consider the structure, its interaction with its surroundings, and associated fatigue problems. Many of the problems are nontrivial in nature, and therefore a combination of experiments, modelling, and numerical analysis must be used. The following research proposal describes an integrated effort through a series of coordinated projects.

PURPOSE AND CONTENTS

Modern society expects the engineering community to provide satisfactory and dependable solutions to a wide variety of problems within the broad area of structural dynamics. The needs go far beyond the traditional image of a regularly vibrating structure. Structures become lighter and more slender and therefore more susceptible to dynamic excitation and response. The dynamic characteristics of light and slender structures depend on the support conditions, and there is an increased demand for realistic descriptions of interaction of structures with foundations (soil) and possibly a surrounding fluid (water/air).

The problems to which solutions are required span widely. The ultimate necessity is safety, that may by endangered either by too a large response, and thereby stress, at a particular time, or by the steady accumulation of damage in the structure. Damage may either be structural damage, as in buildings during earthquakes, or material fatigue, e.g. accompanied by fatigue crack growth. For specially exposed structures, such as large bridges, offshore platforms, communication towers or guyed masts, it may be of interest to monitor the dynamic properties of the structure during the design life to detect potential accumulated damage. In some cases the excitation is man-made, e.g. pile driving close to existing buildings, vibrations from traffic or engine foundations, or noise. In these cases accurate models are needed to impose appropriate limits on the excitation. The acceptable limits may also be comfort or durability criteria.

In traditional structural dynamics, the structure is modelled as an isolated system, that does not interact with its surroundings. The main emphasis was on elastic vibrations, described by stiffness, mass and damping. These properties are simple to measure and to model analytically and numerically. This type of classical structural analysis is in most respects complete. The relative simplicity was obtained by sacrificing several phenomena of increasing importance in recent years: interaction between structure-soil-fluid, more detailed models for dynamic material response, more realistic description of damping. With the more detailed models follows an increasing need for accurate measurements of the interplay of dynamic excitation and response.

Two key features of a comprehensive programme on dynamics of structures are the integration of theory and measurements, and the integration of the disciplines of structural, soil and fluid mechanics. The research programme outlined below aims at this double effect by a concentrated, combined effort of the Department of Building Technology and Structural Engineering and the Department of Civil Engineering at The University of Aalborg (AUC). The programme will have a central position in both departments and involves many of their senior faculty, supplemented by selected external cooperators.

The two departments are in a unique position to undertake such a combined research programme. In 1991 an Experimental Center for Dynamics (Instrumentcenter for Dynamik) was established at the two departments by a grant of 5.2 mill dkr from the National Technical Research Council (STVF). Facilities have been established for generation and measurement and data handling of dynamic excitation and response relating to structures, soils and waves. The related experimental expertise is being established and benefits from an academic position established at the Experimental Center for Dynamics.

PROJECT OUTLINE

The project is organised in three main groups, each comprising three individual projects.

A: Basic theory

A1: Mode Shape and Reduced Base Techniques.
Development of numerical methods and algorithms for large eigenvalue problems, to be used in fluid-structure interaction problems.

A2: Self-induced Oscillations.
Combined theoretical experimental project to describe mechanisms of self-induced transverse oscillations and the corresponding response statistics.

A3: Dynamic Response of Structures with Stochastic Properties and Exciation.
Dvelopment of finite element method for structures with random variation of mateial properties exposed to stochastic loading, e.g. in the form of earthquakes.

B: Experimantal Techniques

B1: Damage Detection in Structures Under Random Loading.
Development of experimental technique based on ARMA time series to identify damage in structures.

B2: Modal Analysis Based on Random Decrement Signatures.
Establishment of a solid theoretical foundation and suitable experimental technique for system identification from the so-called random decrement, i.e. an average of the response sampled after an imposed trig-condition.

B3: Fatigue and Crack Propagation.
Establishment and verification of a theoretical relationship between measurable mateial properties and fatigue crack propagation rate.

C: Selected Structural Problems

C1: Behaviour of Structures Subjected to Dynamic Ground Motion.
Theoretical and experimental investigation of resistance of buildings to dynamic

disturbances propagated through soil, e.g. from pile driving.

C2: Dynamic Response of Coarse Granular Materials to Wave Load.
Theory and experiments to clarify the resistance of monolithic structures founded on coarse soil or rock fill to dynamic wave loads.

C3: Dynamics of Sports Stadiums.
Experimental investigation of mode-shapes etc. for a sports stadium to clarify design assumptions, and development of dynamic spectator load model.

These are the projects covered by the present budget. Towards the end of the programme it is the intention to engage in small projects concerning specific dynamic problems in cooperation with external partners. Likely subjects are: dynamics of guyed masts, bridge cables, wind turbines, or damage detection in wind turbine blades. In order to enable activities of this type the 'expected need for funding' in the main application form is increased for the year 1997.

ORGANIZATION

A leader team will be formed consisting of the leaders of the individual projects, i.e.
- Rune Brincker, Assoc. Prof. (AUC).
- Hans F. Burcharth, Professor (AUC).
- Lars Pilegaard Hansen, Assoc. Prof. (AUC).
- Moust Jacobsen, Professor (AUC).
- Steen Krenk, Professor (AUC).
- Mogens Peter Nielsen, Professor (DTH).
- Søren R.K. Nielsen, Assoc. Prof. (AUC).

This will be the scientific forum, where contact between the various individual projects is established and maintained. It is proposed that Steen Krenk act as program leader, assisted by L. Pilegaard Hansen. An external group will be formed to monitor the progress of the project and provide laison with related research projects, e.g. 'Structural Safety and Reliability'.

BUDGET

The cost of the research programme described above cover approximately six Ph.D. students, external collaboration and visits as described, plus 250.000 kr for two work station computers to the 'Reduced Base Technique' project and the 'Dynamic Ground Motion' project, respectively. Several projects (B1, B2, B3, C1, C2 and C3) rely heavily on experimental equipment supplied by the Experimental Center for Dynamics. This constitutes a considerable contribution but is kept outside the budget, as it is difficult to quantify precisely.

An estimate of the resources provided by the universities amounts to approximately 36 months research time plus 4 months technical assistance devoted to this programme per year, when all projects are active. In addition to the general research effort of faculty at the university AUC has allocated 6 months research work per year in the first three year period specifically for this programme. A Ph.D. grant from AUC in 1994 - 1997 will also be reserved for a subject within the area of 'Dynamics of Structures'. This AUC Ph.D. grant is not included in the total budget of this programme at the present time.

General 'technical staff' for secretarial assistance, drafting and accounts is included corresponding to two days per week for the duration of the programme.

(in 1000 DDK, excl. moms)

Main Budget: Dynamics ofStructures						
	1993	1994	1995	1996	1997	Total
A1:	425	370	355	370		1520
A2:	54	85	45			184
A3:	20	20				40
B1:	155	355	510	380		1400
B2:		160	340	355	185	1040
B3:	365	380	345			1090
C1:		225	355	490	200	1270
C2:	87	290	290	179		846
C3:	160	85	85	45		375
Tech. Staff	85	85	85	85	85	425
Total	1351	2055	2410	1904	470	8190
3% adm.	41	62	72	57	14	246
Total	1392	2117	2482	1961	484	8436
Accum.	1392	3509	5991	7952	8436	

LIST OF PROJECTS

Project Group A: BASIC THEORY

Project A1: Mode Shape and Reduced Base Techniques

A1.1 Motivation

In most numerical models it is necessary to introduce a large number of degrees of freedom in order to represent the structure (and maybe also its surroundings) with sufficient accuracy. It is a common experience that only a small fraction of the possible deformation modes contribute in an essential way to the dynamic response of the structure. The extraction of the essential modes - a so-called 'reduced base' - therefore is an essential part of many computational methods for dynamic response analysis. In recent years the traditional use of the low frequency uncoupled mode shapes are being replaced by more efficient methods of Lanczos or Arnoldi type. In these methods the reduced base is created sequentially by generating a new vector and imposing orthogonality. These methods are now well established for symmetric problems with modal damping. The interesting and important problem types with non-modal damping and/or unsymmetric matrices, that occur e.g. in fluid-structure interaction problems are still active research areas.

A1.2 Objectives

The goal of the project is to develop numerically stable algorithms for dynamic response of large damped symmetric or nonsymmetric systems. Applications from dynamic fluid-structure or acoustic-structure interaction will be considered.

A1.3 Research tasks

The start will be a literature survey of eigenvalue algorithms for dynamic analysis of large structures and fluid-structure interaction. Subsequently the following tasks will be undertaken:

1. The Householder method for tridiagonalisation of a matrix will be extended to simultaneous reduction of two symmetric matrices defining a generalised eigenvalue problem. The algorithm will be implemented on a computer. The algorithm is expected to be numerically stable.

2. A solution of the generalised eigenvalue problem by combination of direct tridiagonalisation and a QR-method will be developed. Criteria for identifying a limited number of modes will be considered.

3. The efficiency and numerical stability of the generalised Householder / QR method will be investigated and compared with the Lanczos algorithm.

4. The more efficient of the algorithms will be implemented in the form of a Reduced Base method.

5. Fluid-structure interaction will be analysed by the above method, and non-proportional damping resulting e.g. from radiation will be considered.

A1.4 Staffing

The project will be caried out at the Deptartment Building Technology and Structural Engineering, AUC. It will have the folllowing staffing:

- Ph.D. student Steffen Vissing (project).
- Professor, Dr.Techn. Steen Krenk (AUC).

In addition Techn.Dr. Håkan Carlsson will participate as visiting research associate from Lund Institute of Technology.

A1.5 Relation to other projects

The project is related to the project 'Interaction between Fluid and Structure; Numerical Models and Their Solutions' carried out at the Division of Structural Mechanics and Division of Engineering Acoustics at Lund Institute of Technology. Collaboration will take place in the form of exchange visits and coordination of research tasks 3 - 5.

A1.6 Budget

(in 1000 DDK, excl. moms, excl. 3% adm.)

Project A1: Mode Shape and Reduced Base Techniques					
	1993	1994	1995	1996	1997
Scientific staff	275	290	305	320	
Technical staff	0	0	0	0	
Equipment	110	30	0	0	
Expenditures	40	50	50	50	
Total	425	370	355	370	
Accumulated	425	755	1150	1520	1520

Notes:

1) Expenditures include travel expenses and expenses for research exchange visits with Lund Institute of Technology.

2) A work station will be purchased 1993 and extended with an external working disk 1994.

A1.7 Time schedule

	1993	1994	1995	1996	1997
1: Householder					
2: QR algorithm					
3: Efficiency					
4: Reduced base					
5: Fluid-structure					

Project A2: Self-induced Oscillations

A2.1 Motivation

Slender and flexible structures or structural elements exposed to flowing wind or water may be susceptible to oscillations generated and sustained by the flowing fluid. Examples are cables, masts, (steel) chimneys and suspended pipelines. The oscillations may render the structure unfit for use and/or lead to unacceptable accumulation of fatigue damage. The problem of wind induced transverse oscillations is still being debated in connection with the coming Eurocode No.1 for Actions on Structures. The key mechanism is the transfer of energy from the fluid flow to the structure, and the generation of a coupled oscillation.

A2.2 Objectives

It is the goal to obtain a theoretical description of a simple mechanical system exhibiting self-induced oscillations and 'phase locking' in the presence of stochastic excitation. A white noise representation of the stochastic input will be tried in order to obtain the joint probability function of displacements and velocities. Theoretical results for occurrence rates and mean duration of oscillations will be sought. Experimental results concerning the oscillation mechanism and the statistics of the oscillations will be obtained in a wind-tunnel and used for verification of the theory.

A2.3 Research tasks

Models in the form of equivalent mechanical systems with 2-3 degrees of freedom will be reviewed from the literature. Subsequently the following tasks will be undertaken:

1. A simple two degrees of freedom model will be developed with a corresponding stochastic representation of the fluid flow.
2. Wind tunnel experiments will be carried out to obtain the fluctuating pressure distribution on a rigid cylinder with one degree of freedom and statistics on the occurrence and duration of oscillations
3. The response statistics of the theoretical model will be investigated, e.g. by numerical integration of the corresponding multi-dimensional Fokker-Planck equation, and comparison wil be made with the experimental results.
4. Additional experiments will be carried out with different degrees of turbulence to study the influence on the oscillations.

A2.4 Staffing

The theoretical part of the project will be caried out at the Deptartment Building Technology and Structural Engineering, AUC. Participants:
- Professor, Dr.Techn. Steen Krenk (AUC).
- Assoc. Prof., Ph.D. S.R.K. Nielsen (AUC).

The experimental part will be carried out by Svend Ole Hansen ApS, Sct. Jørgens Alle 7, København. Ph.D. S. O. Hansen will be participate in the later developments as visiting research associate.

A2.5 Relation to other projects

The experiments mentioned as task 2 are a joint project with the Department of Structural Engineering, Technical University of Denmark, and the STVF sponsored project 'Structural Safety and Reliability' headed by Professor, Dr.Techn. O. Ditlevsen. Close contact will also be maintained in the theoretical work and supplementary experiments.

A2.6 Budget
(in 1000 DDK, excl. moms, excl. 3% adm.)

Project A2: Self-Induced Oscillations					
	1993	1994	1995	1996	1997
Scientific staff	25	60	30		
Technical staff	0	0	0		
Equipment	19	0	0		
Expenditures	10	25	15		
Total	54	85	45		
Accumulated	54	139	184	184	184

Note:
1) Equipment is pressure transducers for wind tunnel experiments.

A2.7 Time schedule

	1993	1994	1995	1996	1997
1: Model					
2: Experiments					
3: Response					
4: Turbulence exp.					

Project A3: Dynamic Response of Structures with Stochastic Properties and Excitation

A3.1 Motivation
Structures exposed to severe loading such as earthquakes and explosion

loads may deteriorate to such an extent that it changes the dynamic properties of the structure. An example is the cracking of concrete beams and plates during earthquakes, where the location and extent of cracks determines the stiffness and damping of the structure. The structural response to a stochastic transient load and the gradual build-up of damage, e.g. in the form of cracking, is an important design consideration for these structures. The actual location of the cracks depend on the tensile strength of the concrete as well as the loading process.

A3.2 Objectives
Development of a finite element method for physically nonlinear structures with highly varying material properties and random dynamic loading. The method will be based on a similar method for reinforced concrete frames subject to earthquake excitation, which is under derivation.

A3.3 Research tasks
As A3.2.

A3.4 Staffing

The project will be carried out jointly at the Department of Building Technology and Structural Engineering, AUC, and Princeton University, USA. Participants:

- Assoc. Prof., Ph.D. S.R.K. Nielsen (AUC)
- Ph.D. student H.U. Köylüoglu (Princeton University).

H.U. Köylüoglu is visiting AUC until August 31, 1993. In the further cooperation it is planned that S.R.K. Nielsen visit Princeton University one month in each of the years 1993 and 1994.

A3.5 Relation to other projects

The project is a continuation of the project 'Material modelling and response of concrete structures with stochastic material parameters subjected to stochastic loading' currently supported by STVF until August 31 1993.

A3.6 Budget

(in 1000 DDK, excl. moms, excl. 3% adm.)

Project A3: Stochastic Properties and Excitation					
	1993	1994	1995	1996	1997
Scientific staff	0	0			
Technical staff	0	0			
Equipment	0	0			
Expenditures	20	20			
Total	20	20			
Accumulated	20	40	40	40	40

Note:

1) Expenditures cover travel expenses and expenses for research exchange visits with Princeton University.

A3.7 Time schedule

Year	1993	1994	1995	1996	1997
FEM model					

Project Group B: EXPERIMENTAL TECHNIQUES

Project B1. Damage Detection in Structures Under Random Loading

B1.1 Motivation

For many structures deterioration caused by fatigue or environmental influence is a serious problem that may reduce the safety and result in early replacement or repair. The conventional methods for detecting and locating structural faults are e.g. ultra sonic testing, radiography, eddy current methods etc. One common disadvantage of these methods is that the components under inspection must be investigated in an exhaustive piecewise manner. Thus these methods are not only time-consuming but inadequate to hard-to- reach locations for large complex structures. To reduce the costs of inspection and provide reliable information about the state of the structure, much research has been initiated the recent years in order to develop techniques to detect, locate and quantify damage in structures by using modal parameters and mode shapes estimated from vibration measurements. Experiences with these methods have led to the conclusion that it is possible to detect faults and in some circumstances also locate faults in structures by using vibration measurements.

B1.2 Objectives

The techniques for detecting faults are mainly based on modal parameters and mode shape information. However these quantities cannot be estimated with complete accuracy due to the inevitable presence of scatter in experimental measurements. One of the most used experimental technique for identification of structural systems is based on calibration of time series of the ARMA-type. One of the goals of the project will be to investigate the uncertainties of the modal parameters and mode shapes obtained by a practical application of ARMA-models on structural problems. The main goal of the investigations is to develop a robust damage detection technique based on calbration of ARMA-models for detecting, locating and quantifying damages in structural systems.

B1.3 Research tasks

The research will continue ongoing work on detection of faults in structures and application of time series models of the ARMA-type for identification of structural systems. This research will consist of following parts:

1. Practical application of ARMA-models will be investigated with respect to the quantification of the uncertainty of the modal parameters as a function of the test data, handling of nonlinearities, design of experiments for optimal information about damages and introduction of prior information about the noise into the identification process.
2. Investigations of the effectiveness and reliability of well-known techniques for detecting and locating damages based on vibration measurements. Further, new techniques, e.g. pattern recognition, will also be investigated and improved.
3. Implementation of damage detecting and locating techniques in order to investigate the applicability on real structures loaded by wind and waves. Much research until now has been based on simulated data and laboratory work.

B1.4 Staffing

The project will be carried out at the Department of Building Technology and Structural Engineering, University of Aalborg, by following staffing:

- Assoc. Prof. Ph.D, Rune Brincker (AUC)
- Senior Assoc. Prof. Ph.D, Lars Pilegaard Hansen (AUC)
- Ass. Prof. Ph.D, Poul Henning Kirkegaard (AUC)

- Ph.D Student (project)

B1.5 Relation to other projects

The project will be performed in cooperation with different partners. The investigations of the ARMA-models used on structural problems will be carried out together with Polytecnico de Torino. Investigations of the effectivity and reliability of the techniques based on vibration measurements for detecting and locating damages in real structures will for a part of the work be done in cooperation with the consultant company Rambøll, Hannemann & Højlund. Further, the instrument manufacturer Brüel & Kjær will cooperate for developing a software package including programmes for identification of structural systems based on time series models of the ARMA-type.

B1.6 Budget

(In thousand DKK. excl. moms, excl. 3% adm.)

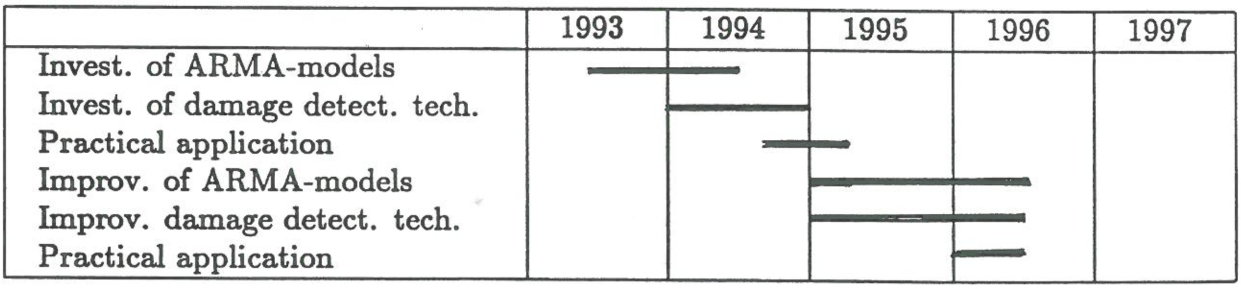
Project B1: Damage Detection in Structures under Random Loading					
	1993	1994	1995	1996	1997
Scientific staff	135	290	445	340	
Technical staff	0	15	15	15	
Equipment	0	0	0	0	
Expenditures	20	50	50	25	
Total	155	355	510	380	
Accumulated	155	510	1020	1400	1400

Notes:

1) Scientific staff includes 1 year's salary 1995-1996 in addition to Ph.D.

2) Expenditures indluce cost of equipment.

B1.7 Time Schedule



Project B2. Modal Analysis Based on Random Decrement Signatures

B2.1 Motivation

The Random Decrement technique for system identification has been known since the late sixties where it was developed in the NASA laboratories. The advantage of the technique is its low estimation time which makes the technique suitable for on-line use. Due to uncertainties in the theoretical background this technique has never found wide-spread use. However, during recent years the basic theory has been developed and tentative studies has shown that in certain circumstances the RDD technique is superior to the Fast Fourier Transform (FFT) technique with respect to speed and accuracy. Preliminary investigations show that for modal parameter estimation the technique might be up to 100 times faster and more accurate than the FFT technique.

B2.2 Objectives

Almost every computer based modal analysis system makes time to frequency domain transformation by using the FFT technique giving biased estimates of the spectral densities, frequency response functions etc. (FRF). Further, one is also faced with problems such as e.g. leakage when the FFT is used. This means that modal parameters estimated also will be biased. One of the goals of the project will be to investigate the applicability of the RDD technique for estimation of frequency domain estimates such as FRF's. Investigations of the applicability of parameter estimation based direct on RDD estimates will be an other goal. The goal of these investigations is a formulation of a technique which can be implemented for multi-output systems.

B2.3 Research Tasks

The starting point will be investigations of the RDD technique in order to obtain a robust technique for implementation. These investigations will be with respect to:

1. trig conditions
2. bias problems
3. lightly damped structures - not lightly damped structures
4. implementation problems

The following research will consist of:

5. parameter estimation by RDD
6. quantification of estimation uncertainties
7. implementation for multi-output systems
8. practical application

B2.4 Staffing

The project will be carried out at the Department of Building Technology and Structural Engineering, University of Aalborg, by following staffing:

- Assoc. Prof. Ph.D, Rune Brincker (AUC).
- Ass. Prof. Ph.D, Poul Henning Kirkegaard (AUC).
- Professor Ph.D, Dr. Techn, Steen Krenk (AUC).
- Ph.D-Student (project).

B2.5 Relation to other projects

The project will continue ongoing work on the theoretical basis of the random decrement technique at the University of Aalborg. An informal contact to professor Ibrahim from Old Dominion University, USA who has formulated a similar technique based on free decay measurements known as the Ibrahim time domain technique (ITD) is expected to be extended to active cooperation including exchange visits.

B2.6 Budget

(In thousand DKK. excl. moms, excl. 3 % adm.)

Project B2: Modal Analysis Based on Random Decrement Signatures					
	1993	1994	1995	1996	1997
Scientific staff		140	290	305	165
Technical staff		0	0	0	0
Equipment		0	0	0	0
Expenditures		20	50	50	20
Total		160	340	355	185
Accumulated		160	500	855	1040

Note:
Expenditures include cost of equipment.

B2.7 Time Schedule

	1993	1994	1995	1996	1997
1: Trig conditions					
2: Bias problems					
3: Lightly damped structures					
4: Implementation problems					
5: Parameter estimation by RDD					
6: Quantification of uncertainties					
7: Multi-output systems					
8: Practical application					

Project: B3. Fatigue and Crack Propagation

B3.1 Motivation

Fatigue crack growth is a main cause of failure in steel structures. Traditionally the crack growth is determined by empirical formulas with experimentally calibrated parameters. A new theoretical formula based on an energy balance criterium has recently been proposed by professor M. P. Nielsen, Department of Structural Engineering, DtH. The advantage of this theoretical based formula is that many tests can be avoided in the future when the mechanics properties for the material are known.

B3.2 Objectives

The aim is to investigate crack propagation problems on the basis of the previously mentioned formula. The formula will be applied to steel and perhaps some other materials for example concrete. Some work with the formula has been carried out in 1992 with very promising results but many questions are still unanswered. Based on the knowledge obtained until now it is the idea to apply/transfer this knowledge to practical structures or parts of structures for example welded connections.

B3.3 Research tasks

1. The starting point is the new formula for fatigue crack growth and, in relation to this formula, some tests carried out in the summer/autumn 1992. These tests revealed a new relation between the critical value of the stress intensity factor, K_{Ic}, and the actual value of the stress intensity factor, K_I during the fatigue test. Continuation of the tests on steel specimens from the summer/autumn 1992 to determine a more precisely relation between K_{Ic} and K_I.

2. Fatigue tests concerning welded steel connections are of great practical importance. Theory and tests results from the studies of the model on fatigue crack growth (see 1. above) will be used in the study of the fatigue process for connections. Examples (perhaps in a minor scale) from practical construction of steel structures will be tested.

3. In connection with the study of crack growth under the fatigue process it is of great importance to measure the crack length in a suitable way. A Ph.D. study from 1989 to 1992 at AUC had as one result the development of a digital image processing system for crack length measurement. It is intended to extend this system and use the system whenever possible in all the above mentioned experiments.

4. It will be desirable to use the theory on more complicated structural systems, run tests with these more complicated systems and to develope a general computer program for crack growth problems.

5. Brittle materials as for example concrete are especially crack growth sensitive in uniaxial compression. If time permits it will be interesting to examine the crack patterns known from experiments with brittle materials applying to the new formula. Also a combined mode I and mode II phenomenon will be interesting to examine and in this way determine crack growth in concrete loaded in shear and bending.

6. Reports are written for the subjects mentioned above and a final report is written in the last half year of the project time.

B4.4 Staffing

The present study will form the basis for a Ph.D. study at the Department of Strutural Engineering, DtH funded by this programme. The supervisor will be professor, dr. techn. M. P. Nielsen and the Ph.D. student will be M.Sc. Thomas Cornelius Hansen, who has been working with these problems in 1992.

Experimental work is necessary to conform the theory and most of the tests will be carried out at the Department of Building Technology and Structural Engineering, AUC. From this department Lise Gansted, Rune Brincker and Lars Pilegaard Hansen will participate in the project.

The project will be carried out in the form of a Ph.D. study at the Department of Structural Engineering, Technical University of Denmark with Professor, Dr.Techn. M.P. Nielsen as supervisor. The experiments will be carried out at the Department of Building Technology and Structural Engineering, University of Aalborg. The participants are:

- Ph.D-Student Thomas Cornelius Hansen (project).
- Professor Dr.Techn., M.P. Nielsen (DTH).
- Assoc. Prof. Ph.D, Lars Pilegaard Hansen (AUC).
- Assoc. Prof. Ph.D, Rune Brincker (AUC).
- Ass. Prof. Ph.D, Lise Gansted (AUC).

B3.5 Relation to other projects

The project is a continuation of work carried out in fatigue and experimental techniques at DtH and AUC by the persons mentioned in section 4.

B3.6 Budget

(In thousands of DKK, excl. moms, excl. 3% adm.)

Project B3: Fatigue and Crack Propagation					
	1993	1994	1995	1996	1997
Scientific staff	275	290	305		
Technical staff	30	30	20		
Equipment	0	0	0		
Expenditures	60	60	20		
Total	365	380	345		
Accumulated	365	745	1090	1090	1090

Note:
1) Expenditures include travels, test specimens, etc.

B3.7 Time schedule

	1993	1994	1995	1996	1997
1: K_{Ic}, K_I-relation					
2: Welded connections					
3: Image processing					
4: "Complicated" systems					
5: Brittle materials					
6: Final report					

Project Group C: SELECTED STRUCTURAL PROBLEMS

Project C1: Behaviour of structures subjected to dynamic ground motion

C1.1 Motivation

Many structures are subjected to critical dynamic loads generated by wind, waves or ground motions. The most heavy ground motions are caused by earth quakes or explosions which are not common in Denmark, but also ground motions from heavy traffic, machines or pile driving may damage buildings, especially the older ones situated in urban areas with soft subsoils. The degree of damage depends on the soil layers involved in the problem. Some soil layer can magnify the amplitude of specific frequencies, other soil layers can build up pore pressure, which may liquefy part of the subsoil and cause permanent settlements of the soil surface.

These phenomena have not been studied in detail until now due to a lack of suitable equipment. The establishment of the Experimental Center for Dynamics enables AUC to use very advanced equipment and numerical calculations in analysing these problems.

C1.2 Objectives

It is necessary to understand the following phenomena in order to overcome the problem:

The generation of shear and compression waves by shock loading of piles. The vertical and horizontal movements of piles during driving. The importance of skin friction, tip resistance or pile damages.

Propagation of surface waves in layered soils or soils with elasticity increasing with depth. The ground water table as a reflector.

Energy dissipation in layered soils with damping and non-constant stiffness. Energy transfer in interface between soil and foundation.

Interaction between vibrating structure and soil.

C1.3 Research programme

The programme consists of theoretical surveys and considerations, in situ measurements which include a comprehensive pilot project followed by normal measuring projects and advanced numerical calculations.

1. Literature study of progression of shock waves in solids as reported by specialists in geophysics, earth quake engineering and soil mechanics.

2. Pilot project: Initial series of observations of propagation of shock waves in piles during driving, of surface waves (Rayleigh waves) and in buildings or other neighbouring structures. The purpose is to find an optimal instrumentation and measuring methodology to be used at sites with vibration problems. This part of the program will be carried out in close cooperation with CP-tests in Vejle, where they have many years experience in pile driving analysis comprising measure of shock waves in piles and numerical analysis.

3. Selection of possible measuring sites which cover a wide range of typical Danish soil conditions and elaboration of a measuring program for each site. The purpose is to ensure a smooth cooperation with CP-tests including use of unexpected possibilities to get further information.

4. In situ field investigations and observations (from 3.)

5. Analysis of data by means of numerical methods, such as finite elements and simple energy dissipation theories. Set up of a final conclusion.

6. Report (Thesis).

7. Further research work.
   The programmed research may need to be followed by another program concerning measurements of appropriate soil properties by vibrating columns of soil (resonans colomb tests) and dynamic triaxial tests. The dynamic properties of Danish soil are still unknown for most of the soil types.

C1.4 Staffing

The project will be carried out at the Department of Civil Engineering, AUC in cooperation with the Department of Building Technology and Structural Engineering and CP-tests. The staff will be

- Ph.D. student (project).
- Assistant professor, Lars Bo Ibsen (AUC).
- Professor, lic.techn. Moust Jacobsen (AUC).
- Professor, Dr.techn. Steen Krenk (AUC).
- Engineer, M.Sc. Rikard Skov (CP-tests).

C1.5 Relation to other projects

The project is related to the Ph.D. work of Lars Bo Ibsen, which will be finished by December 1, and to the LITAEIS program, which includes the University of Århus and several German universities.

C1.6 Budget

(in 1000 DKK excl. moms, excl. 3% adm.)

Project C1: Behaviour of Structures Subjected to Dynamic Ground Motion					
Year	1993	1994	1995	1996	1997
Scientific staff		140	290	305	160
Technicians		15	15	15	10
Equipment		40	0	120	
Expenditures		30	50	50	30
Total		225	355	490	200
Accumulated		225	580	1070	1270

Notes:

1) Expenditures include expenses connected with field investigations, mainly travelling and cooperation with CP-tests and external specialists.

2) Equipment includes a workstation and data acquisition equipment.

C1.7 Time schedule

Year	1993	1994	1995	1996	1997
1. Literature study					
2. Pilot project					
3. Selection					
4. In situ investigation					
5. Analysis of data					
6. Report					

C2. Dynamic Response of Coarse Granular Materials to Wave Load

C2.1 Motivation

Many types of coastal structures resist the wave action by heavy monolithic members, such as caissons, placed on quarry rock materials. The most common example is vertical wall breakwater structures the function of which depends almost entirely on resistance to wave action. The complicated interaction between the high-frequency wave loads and the structural respons is poorly known mainly because the dynamic strength and deformation characteristics of quarry run (coarse soil materials) are hardly known. Consequently, only some very primitive design methods are used today. Considering the enormous costs of this kind of structures it is important to improve the theoretical basis for design methods. The newly established centre for dynamic studies within civil engineering at AUC provides the ideal background for the study of the problems.

C2.2 Objectives

The overall objective is to develop a rational method for the design of concrete superstructures on rubble mound breakwaters and the design of monolithic caisson structures on rubble foundation. The special contribution from the present project is mainly to provide the soil mechanics part of the design tools.

C2.3 Research programme

The programme contains both theoretical and experimental work. The following main tasks will be performed:

1. Literature study of theories and experimental results related to dynamic response and strength characteristics of coarse soils (quarry run and quarry stones). This part of the study includes contacts with researchers outside Denmark, e.g. in Germany and Japan.

2. Experimental determination of strength and deformation characteristics of coarse granular materials, based on laboratory experiments with samples.

3. Studies of wave loads on relatively stiff monolithic structures. This part includes hydraulic model tests as well as an analysis of existing wave load signals from other laboratories.

4. Formulation of theoretical model(s) for the interaction between the wave loads and the response of structure and foundation (soil response).

5. Experimental verification of theoretical model(s) for the interaction between wave load, structure and foundation (soils).

6. Report (thesis) including critical review of obtained results and, hopefully, some practical engineering recommendations.

C2.4 Staffing

The project will be carried out at the Department of Civil Engineering, Aalborg University. Cooperation with University of Hannover and The Ports and Harbour Research Institute in Japan is planned (see below). The project is very suitable for a Ph.D. study. The staff from Aalborg University will be

- 1 Ph.D. student (project)
- Professor H.F. Burcharth (AUC)
- Professor H. Moust Jacobsen (AUC)
- Ass. prof. Lars Bo Ibsen (AUC)
- Ass. prof. Peter B. Frigaard (AUC)

C2.5 Relation to other projects

The project is related to the coming Marine Science and Technology II Programme, which will start primo 1993. Part of the expenses will be covered through this project (salaries app. 180.000 DKK + some travelling expenses). The project is also coordinated with the work of an international group on Vertical Wall Breakwaters. This group is formed by PIANC and involves the important Japanese experience in the field.

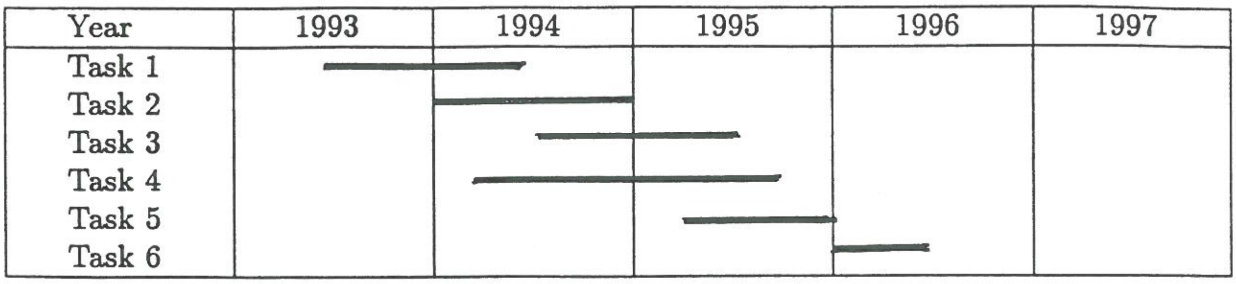
C2.6 Budget

(in 1000 DKK, excl. moms, excl. 3% adm.)

Project C2: Dynamic Response to Coarse Granular Materials to Wave Load					
	1993	1994	1995	1996	1997
Scientific staff	72	215	215	143	
Technical staff		30	30	10	
Equipment					
Expenditures	15	45	45	26	
Total	87	290	290	179	
Accumulated	87	377	667	846	846

Note:
Salary 1 Ph.D. in 3 years, financial contribution from MAST II 180.000 DKK.

C2.7 Time schedule



Project C3: Dynamics of Sports Stadiums

3.1 Motivation

In the current design of sports stadiums dynamic effects constitute an important part. The dynamic loads are partly external, mainly from wind, and partly imposed by spectator movement. In both cases a good representation of the dynamic properties of stadium as well as the load is necessary. These issues are currently discussed in design code committees, and improved knowledge is desirable. The newly completed sports stadium 'Parken' in København could serve as basis for an investigation of typical dynamic design assumptions and development of a dynamic spectator load model. Part of the necessary dynamic measurement equipment, such as accelerometers and wind measurement devices, can be obtained from the Experimental Center for Dynamics.

C3.2 Objectives

An investigation of the validity of typical dynamic design assumptions for sports stadiums regarding eigenfrequencies, mode shapes, aerodynamic and mechanical damping, and amplitudes. Development of a dynamic spectator load model that gives a realistic representation of the dynamic force (or impulse) and its spatial distribution.

C3.3 Research tasks

Relevant codes of practice will be consulted and background literature reviewed. The project will consist of:

1. A measurement program on the sports stadium 'Parken' to describe dynamic response to high winds, sports events and concerts.

2. Comparison of measured dynamic response data with computer models.

3. Development of a model for the dynamic load from spectator movement including its time dependence and spatial distribution.

C3.4 Staffing

The project will be caried out in collaboration between the Department of Building Technology and Structural Engineering, AUC, and Svend Ole Hansen ApS, Sct. Jørgens Alle 7, København. Participants:
- Ph.D. Svend Ole Hansen (SOH ApS).
- Assoc. Prof. Ph.D. Lars Pilegaard Hansen (AUC).

- Ass. Prof. Ph.D, Poul Henning Kirkegaard (AUC).
- Ass. Prof. Ph.D. Jeppe Jønsson (AUC).
- Professor, Dr.Techn. Steen Krenk (AUC).

C3.5 Relation to other projects

The work is of current interest to the Danish Code Committee for loads on structures.

C3.6 Budget

(in 1000 DDK, excl. moms, excl. 3% adm.)

Project C3: Dynamics of Sports Stadiums					
	1993	1994	1995	1996	1997
Scientific staff	60	60	60	30	
Technical staff	10	10	10	0	
Equipment	75	0	0		
Expenditures	15	15	15	15	
Total	160	85	85	45	
Accumulated	160	245	330	375	330

Notes:

1) Equipment includes a data aquisition computer, 2 accelerometers and wind measurement devices.

2) Expenditures include travel and expenses from carrying out measurements at a distant location.

C3.7 Time schedule

	1993	1994	1995	1996	1997
1: Esperiments					
2: Analysis					
3: Load model					

SENIOR PARTICIPANTS

The following gives a brief summary of the senior participants. More extensive resumees with a list of recent publications is given in Annex A.

Rune Brincker: associate professor, Ph.D., M.Sc., Department of Building Technology and Structural Engineering, AUC. Main research areas: Fracture mechanics, experimental techniques, experimental dynamics. Numerous publications on experimental mechanics. Associated with the Experimental Center for Dynamics at AUC.

Hans F. Burcharth: professor, Department of Civil Engineering. Main research areas: hydrodynamics, hydraulics, coastal and offshore engineering. Author of numerous journal articles and two books on port and coastal engineering and coastal morphology. Member of the PIANC international working group for implementation of safety in coastal structures.

Lars Pilegaard Hansen: senior associate professor, Ph.D., M.Sc., Department of Building Technology and Structural Engineering, AUC. Main research areas: experimental mechanics, fatigue of concrete structures. Head of the Experimental Center for Dynamics at AUC.

Moust Jacobsen: professor, M.Sc., Ph.D. Department of Civil Engineering, AUC. Main research areas: Developement of measuring devices for soil elements, soil behaviour, and soil-structure interaction. Author of textbooks in advanced Soil Mechanics and many conference papers, co-author of textbooks onn Soil Mechanics and Foundation Engineering.

Steen Krenk: professor, Ph.D., Dr.Techn., Department of Building Technology and Structural Engineering, AUC. Main research areas: structural and applied mechanics, numerical methods, and stochastic mechanics. Author of numerous journal articles and co-author of two books on safety of structures. Member of national and international code committees on loads on structures.

Mogens Peter Nielsen: professor Ph.D., Dr.Techn., Department of Structural Engineering, Technical University of Denmark. Main research areas: Applied mechanics, in particular development of design methods for concrete structures using plasticity theory. Author of numerous journal articles and a book on concrete structures. Member of international code committees on concrete structures.

Søren R. K. Nielsen: senior associate professor, Ph.D., Department of Building Technology and Structural Engineering, AUC. Main research areas: structural dynamics, and stochastic mechanics. Author of numerous journal articles and conference contributions. Experience with theory and computer programs for guyed masts.

Aalborg October 14, 1992

On behalf of the project team

Steen Krenk

ANNEX A: Resume of Senior Participants

Curriculum Vitae for Rune Brincker

Rune Brincker, M.Sc. (1977), Ph.D. (1982), B.Com. (1989).
Senior lecturer in structural engineering at the Institute of Building Technology and Structural Engineering at AUC since 1985. Research engineer at the Department of Structural Engineering at the Technical University of Denmark 1982-1985.
Main research areas: Fracture mechanics, experimental techniques, experimental dynamics.

Periodicals

1. J.D. Sørensen & R. Brincker: Simulation of Stochastic Loads for Fatigue Experiments. *Experimental Mechanics*, June 1989, pp 174–182.

2. R. Brincker & J.D. Sørensen: High-Speed Stochastic Fatigue Testing. *Experimental Mechanics*, March 1990, pp 4–9.

3. R. Brincker & H. Dahl: On the Fictitious Crack Model of Concrete Fracture. *Magazine of Concrete Research*, Vol. 41, No. 147, June 1989, pp 79–86.

4. P.H. Kirkegaard, I. Enevoldsen, J.D. Sørensen & R. Brincker: Reliability Analysis of a Mono-Tower Platform. *Journal of Offshore Mechanics and Arctic Engineering*, ASME, Vol. 112, Aug. 1990, pp 237–243.

5. P.H. Kirkegaard, J.D. Sørensen & R. Brincker: Fatigue Reliability Analysis of a Mono-Tower Platform. *Marine Structures*, Vol. 4, 1991, pp 413–434.

6. L. Gansted, R. Brincker & L. Pilegaard Hansen: Fracture Mechanical Markov Chain Crack Growth Model. *Engineering Fracture Mechanics*, Vol. 38, No. 6, 1991, pp 475–489.

7. R. Brincker, S. Krenk, P. H. Kirkegaard & A. Rytter: Identification of Dynamical Properties From Correlation Function Estimates. *Bygningsstatiske Meddelelser*, Vol. 63, 1992.

8. A. Rytter, R. Brincker & L. Pilegaard Hansen: Vibration based Inspection of Civil Engineering Structures. *Bygningsstatiske Meddelelser*, Vol 62 No. 4, 1991.

9. J. Laigaard Jensen, P. H. Kirkegaard & R. Brincker: Modal and Wave Load Identification by ARMA Calibration. *Journal of Engineering Mechanics*, Vol. 118 No. 6, June 92.

International Conferences

1. J. Laigaard Jensen, R. Brincker & A. Rytter: Identification of Light Damping in Structures. *Eighth International Modal Analysis Conference*, Jan. 29 – Febr. 1, 1990, Orlando, Florida, USA.

2. J. Laigaard Jensen, R. Brincker & A. Rytter: Uncertainty of Modal Parameters Estimated by ARMA Models. *Proc. of The 9th International Conference on*

Experimental Mechanics, August 20-24, 1990, Copenhagen, Denmark, pp 2095–2104.

3. R. Brincker, J. Laigaard Jensen & S. Krenk: Spectral Estimation by the Random Dec Technique. *Proc. of The 9th International Conference on Experimental Mechanics*, August 20-24, 1990, Copenhagen, Denmark, pp 2049–2058.

4. P.H. Kirkegaard, J.D. SØrensen & R. Brincker: Optimization of Measurements on Dynamically Sensitive Structures Using a Reliability Approach. *Proc. of The 9th International Conference on Experimental Mechanics*, August 20-24, 1990, Copenhagen, Denmark, pp 967–976.

5. R. Brincker, S. Krenk & J. Laigaard Jensen: Estimation of Cross Correlation Functions by the Random Decrement Technique. *Proc. of the 9th International Modal Analysis Conference and Exhibit*, Firenze, Italy, April 14-18, 1991, pp 610–615.

6. P. H. Kirkegaard, J. D. SØrensen & R. Brincker: Optimal Design of Measurement Programs for the Parameter Identification of Dynamic Systems. *Proc. of the Florence Modal Analysis Conference*, Firenze, Italy, September 10-12, 1991, pp 495–502.

7. A. Rytter, R. Bbrincker & L. Pilegaard Hansen: Detection of Damage in a Steel Member. *Proc. of the Florence Modal Analysis Conference*, Firenze, Italy, September 10-12, 1991, pp 373–380.

8. R. Brincker, P. H. Kirkegaard & A. Rytter: Identification of System Parameters by the Random Decrement Technique. *Proc. of the Florence Modal Analysis Conference*, Firenze, Italy, September 10-12, 1991, pp 465–472.

Curriculum Vitae for Lars Pilegaard Hansen

Ph.D., M.Sc., senior associate professor, Department of Building Technology and Structural Engineering, AUC. Head of the Experimental Dynamics Laboratory at AUC since its start in 1991. Main research areas: experimental mechanics, fatigue of concrete structures.

Periodicals

1. L. Gansted, R. Brincker & L. Pilegaard Hansen: Fracture Mechanical Markov Chain Crack Growth Model. *Engineering Fracture Mechanics*, Vol. 38, No. 6, pp. 475-489, 1991.

International Conferences

1. L. Pilegaard Hansen: Preliminary Fatigue Tests of Concrete Reinforced with Steel Fibres. *Nordic mini seminar in Gøteborg*, Chalmers Tekniska Høgskola, P-90:8, pp. 37-49, 1989.

2. J. Laigaard Jensen, A. Rytter & L. Pilegaard Hansen: System Identification from Output Measurements. *Eighth International Conference, Society for Experimental Mechanics*, Orlando, Florida, USA, 1990.

3. L. Pilegaard Hansen: Experimental Investigation of Fatigue Properties of Laminated Wood Beams. *International Timber Engineering Conference*, London, pp. 4.203-4.210, 1991.

4. A. Rytter, R. Brincker & L.ars Pilegaard Hansen: Detection of damage in a steel member. *Proc. of the Florence Modal Analysis Conference*, Firenze, Italy, September 10-12, pp. 373-380, 1991.

Curriculum Vitae for Moust Jacobsen

Moust Jacobsen, M.Sc., Ph.D. in Soil Mechanics from the Technical University of Denmark 1968.Research engineer and Ph.D. student at the Foundation Laboratory 1961-1969. Associate professor at the Danish Engineering Academy in Aalborg 1969-1974, senior associate professor at AUC 1974-1989, professor of Soil Mechanics at AUC 1989- . Main research areas: Developement of measuring devices for soil elements, investigation of soil behaviour, research, calculations and observations of soil-structure interaction. Author of textbooks in advanced Soil Mechanics and many conference papers, co-author of textbooks in Soil Mechanics and Foundation Engineering. Supervisor of 5 Ph.D. students, including two studying geodynamical problems.

Textbook

Textbook in Advanced Soil Mechanics, Vol. 3:
M. Jacobsen: *Wave Propagation and Vibration in Soils*, 1990. First textbook in Geodynamics in Denmark.

Periodicals

1. M. Jacobsen: Shear Strength of Unisized Gravels under Triaxial Compression. *Soils and Foundation*, Vol. 30, No. 2. Japanese Soc. of Soil Mech. and Found. Eng. 1992.

Conference Papers

1. M. Jacobsen: In Situ Study of Road Reinforcement by Geotextiles. *XII ICSMFE*, Rio de Janeiro, 1989.

2. M. Jacobsen: Dilatancy and Cohesion in Frictional Material. *XII ICSMFE TC 13*, Rio de Janeiro, 1989.

3. M. Jacobsen & L.B. Ibsen: Developement of Pore Pressure in Cohesionless Soils with Initial Shear Stresses uring Cyclic Loading. *III YGEC*, Minsk, USSR, 1989.

4. M. Jacobsen , S. R. K. Nielsen, P. Thoft-Christensen: Reliability of Soil Sublayers under Earthquake Excitation: Markov Approach. Structural Dynamics and Soil Interaction. *IV Int. Conf. Soil Dyn. and Earthquake Eng.*, Mexico City, 1989.

5. M. Jacobsen: Basic Phenomena in Cyclic Behaviour of Soil. *IX Nat. Conf. Soil Mech. and Found.Eng.*, Cracow, Poland, 1990.

6. M. Jacobsen, L. B. Ibsen: Developement of Pore Pressure and Material Damping during Cyclic Loading. *X ECSMFE*, Firenze, 1991.

7. M. Jacobsen: Karakteristiske belastningstilstande for moræneler. *XI NGM*, Aalborg, 1992.

8. M. Jacobsen: Bestemmelse af forbelastningstryk. *XI NGM*, Aalborg, 1992.

Curriculum Vitae for Steen Krenk

Steen Krenk, M.Sc., Ph.D, Dr.Techn., professor of computational mechanics at AUC since 1989. Research Engineer (later Section Head) Structural Mechanics Section, Research Establishment Risø 1975-1985. Associate Professor at the Technical University of Denmark 1985-1989. Various visiting appointments at North American universities. Main research areas: structural and applied mechanics, numerical methods, and stochastic mechanics. Author of numerous technical papers and co-author of two books on safety of structures. Member of national and international code committees on loads on structures.

Periodicals

1. P. Bjerager & S. Krenk: Parametric Sensitivity in First Order Reliability Analysis, *Journal of Engineering Mechanics*, Vol. 115, 1577-1582, 1989.

2. S. Krenk & B. Jeppesen: Finite Elements for Beam Cross Sections of Moderate Thickness, *Computers & Structures*, Vol. 32, 1035-1043, 1989.

3. S. Krenk & H. Gluver: A Markov Matrix for Fatigue Load Simulation and Rainflow Range Evaluation, *Structural Safety*, Vol. 6, 247-258, 1989.

4. S. Krenk: Constrained Lateral Buckling of I-Beam Gable Frames, *Journal of Structural Engineering*, Vol. 116, 3268-3284, 1990.

5. S. Krenk & L. Damkilde: Warping of Joints in I-Beam Assemblages, *Journal of Engineering Mechanics*, Vol. 117, 2457-2474, 1991.

6. S. Krenk & L. Damkilde: Verformung und Steifigkeit von I-Trägerverbindungen, *Stahlbau*. (in press)

7. S. Krenk: Energy Release Rate of Symmetric Adhesive Joints, *Engineering Fracture Mechanics*. (in press)

8. S. Krenk: Kraftoptagelse i afstivede rammehjørner, *Bygningsstatiske Meddelelser*. (in press)

International Conferences

1. S. Krenk, P. Gerstoft & O. Vilmann: Computational Aspects of Synthetic Seismograms for Layered Media, *59th Annual International SEG Meeting*, October 29 - November 2, Dallas, 1989.

2. P. Gerstoft, O. Vilmann & S. Krenk: Synthetic Seismograms for Layered Media, *Acoustical Society of America Annual Meeting*, November 27-30, St. Louis, 1989.

3. S. Krenk & H. Gluver: Markov Models and Range Counting in Random Fatigue, *Structural Dynamics*, Proceedings of the European Conference on Structural Dy-

namics EURODYN'90, 5-7 June 1990, Bochum, Balkema, Rotterdam, 1991.

4. R. Brincher, J. L. Jensen & S. Krenk: Spectral Estimation by the Random DEC Technique, *9th International Conference on Experimental Mechanics*, Lyngby, August 20-24, 1990.

5. S. Krenk & L. Damkilde: Models of Thin-Walled Beam Connections, *IUTAM Symposium on Contact Loading and Local Effects in Thin-Walled Plated and Shell Structures*, Prague, September 4-7, 1990.

6. J. P. Ulfkjær, R. Brincker & S. Krenk: Analytical Model for Complete Moment-Rotation Curves of Concrete Beams in Bending, *8th European Conference on Fracture: Fracture Behaviour and Design of Materials and Structures*, Torino, October 1-5, 1990.

Curriculum Vitae for M. P. Nielsen

M. P. Nielsen, M.Sc., Ph.D. Dr.Techn., professor of reinforced concrete structures at the Technical University of Denmark since 1972. Lecturer in pure and applied mechanics at the Danish Engineering Academy, Aalborg 1966-1972, Partner and managing director of AEC, Consulting Engineers LtD since 1974. Main researc areas: Applied mechanics especially development of design methods for concrete structures using plasticity theory. Member of international code committees on concrete structures.

Periodicals

1. B. S. Andreassen & M. P. Nielsen: Dome Effect in Reinforced Concrete Two-Way Slabs. *Bygningsstatiske Meddelelser*, Vol. 60, No. 3-4, pp. 79-120, 1989.

2. B. Feddersen & M. P. Nielsen: Dimensionering af betonbjælkers veder- lag. *Dansk Beton*, No. 3, pp. 19-24, 1990, No. 4, pp. 10-13, 1990.

3. Y. Xiaoqing, N. S. Ottosen, S. Thelandersson & M. P. Nielsen: Review of Constitutive Models for Concrete. *Commision of the European Communities, Nuclear Science and Technology, Shared Cost Action, Reactor Safety Program 1985-87. Final Report*, ISPRA, 1989.

4. M. P. Nielsen: An Energy Balance Crack Growth Formula. Bygningssta- tiske Meddelelser, Vol. 61, No. 3-4, pp. 71-125, 1990.

International Conferences

1. M. P. Nielsen: Concrete Beams Shear Design according to Eurocode 2. *Int. Symp. on Concrete Eng.*, Southeast University, Nanjing, China, pp. 1949-1954, 1991.

Curriculum Vitae for Søren R.K. Nielsen

Søren R.K. Nielsen, M.Sc., Ph.D. in Structural Engineering from the Technical University of Denmark, 1974. Project engineer 1974-1978 (COWI-Consult, Denmark). Postdoctoral studies at the University of Aalborg 1978-1981. Project engineer 1981-1984 (Rambøll & Hannemann, Denmark). Lecturer in fluid mechanics and offshore engineering at the University of Aalborg 1984-1986. Lecturer in vibration theory at the University of Aalborg since 1986. Visiting fellow at the Technical university of Wroclaw, Poland in 1988 and 1992, and at the Princeton University, USA in 1990 and 1991. Supervisor of two completed Ph.D. projects in stochastic vibration theory and active vibration control of civil engineering structures. At present engaged in a joint project with researchers at the Princeton University, USA on damage assessment and response analysis of reinforced concrete structures subjected to non-stationary loading processes.

Periodicals

1. R. Iwankiewicz, S. R. K. Nielsen: "Dynamic Response of Non-Linear Systems to Poisson-Distributed Random Impulses". *Journal of Sound and Vibration.* (in press).

2. R. Iwankiewicz, S. R. K. Nielsen: "Dynamic Response of Hysteretic Structures to Poisson-Distributed Pulse Trains". *Probabilistic Engineering Mechanics.* (in press).

3. R. Iwankiewicz, S. R. K. Nielsen, P. Thoft-Christensen: "Dynamic Response of Non-Linear Systems to Poisson-Distributed Pulse Trains: Markov Approach". *Structural Safety*, Vol. 8, 1990, pp. 223-238.

4. K. J. Mørk: "Stochastic Analysis of Reinforced Concrete Frames under Seismic Excitation". November 1991. *Soil Dynamics and Earthquake Engineering* (in press).

5. S. R. K. Nielsen, K. J. Mørk, P. Thoft-Christensen: "Stochastic Response of Hysteretic Systems". *Structural Safety*, Vol. 9, 1990, pp.59-71.

6. S. R. K. Nielsen, K. J. Mørk, P. Thoft-Christensen: "Response Analysis of Hysteretic Multi-Storey Frames under Earthquake Excitation". *Earthquake Engineering and Structural Dynamics*, Vol. 18, 1989, pp. 655-666.

7. S. R. K. Nielsen: "Approximations to the Probability of Failure in Random Vibration by Integral Equation Methods". *J. Sound Vib.*, Vol. 137, No. 2, 1990, pp. 305-317.

8. S. R. K. Nielsen, K. J. Mørk, P. Thoft-Christensen: "Reliability of Hysteretic Systems Subjected to White Noise Excitation". *Structural Safety*, Vol. 8, 1990, pp. 369-379.

9. G. Sigurdsson, S. R. K. Nielsen: "Stress-Response of Offshore Structures by Equivalent Polynomial Expansion Techniques". *Int. J. of Offshore and Polar Engng.*, Vol. 1, No. 1, March 1991, pp. 71-76.

International Conferences

1. R. Iwankiewicz, S. R. K. Nielsen, P. Thoft-Christensen: "Dynamic Response of Hysteretic Structures to Random Pulse Trains: Markov Approach". *5th ICOSSAR Conference*, San Francisco, USA, August, 1989.

2. R. Iwankiewicz, S. R. K. Nielsen: "Dynamic Response of Non-Linear Inelastic

Systems to Poisson-Driven Stochastic Excitations". *Proceedings of 1st COSMEX Meeting on "Stochastic Methods in Experimental Sciences"*, Szklarska Poreba, Poland, September 8-14, 1989, *World Scientific*, 1990, pp. 200-209.

3. K. J. Mørk, S. R. K. Nielsen: "Reliability of Soil Sublayers under Earthquake Excitation". *Proceedings of the EURODYN'90 conference on "Structural Dynamics"*, Bochum, FR Germany, June 5-7, 1990, Balkema, 1991, pp. 225-235.

4. S. R. K. Nielsen, P. Thoft-Christensen, H. Moust Jacobsen: "Reliability of Soil Sublayers under Earthquake Excitation: Markov Approach". *Proceedings of the 4th Int. Conf. on Soil Dynamics and Earthquake Engineering on "Structural Dynamics and Soil-Structure Interaction"*, Mexico City, Mexico, October 23-26, 1989, pp. 19-37.

5. S. R. k. Nielsen, A. S. Cakmak: "Evaluation of Maximum Softening as a Damage Indicator for Reinforced Concrete under Seismic Excitation". *Proceedings of the 1st Int. Conf. on Computational Stochastic Methods*, Corfu, Greece, September 17-19, 1991, Elsevier Applied Science, 1991, pp. 169-184.

6. K. J. Mørk, S. R. K. Nielsen: "System Reduction for Random Dynamically Loaded Elasto-Plastic Structures". *Proceedings of the 1st Scandinavian Forum for Stochastic Mechanics*, Lund, Sweden, August 30-31, 1990, Swedish Council for Building Research, Stockholm, 1991, pp. 145-157.

7. S. R. K. Nielsen: "Dynamic Response Analysis of Non-Linear Inelastic Systems Based on Stochastic Differential Equations". *Proceedings of the 1st Scandinavian Forum for Stochastic Mechanics*, Lund, Sweden, August 30-31, 1990, Swedish Council for Building Research, Stockholm, 1991, pp. 15-24.

CURRICULUM VITAE (resumé)

Navn:	Knut H. Andersen
Fødselsdato:	28. december 1945
Nationalitet:	Norsk
Stilling:	Afdelingsleder (Analyse og Modellering) Norges Geotekniske Institut Postboks 3930 Ullevål Hageby 0806 Oslo
Uddannelse:	Civilingeniør, Norges Tekniske Højskole, 1968.
Kvalifikationer:	(udvalg): Omfattende erfaring med forskning, udvikling og konsulentvirksomhed inden for fundering af offshore konstruktioner (graviations- og 'tension leg' platforme), samt med cyklisk belastning af jord. Virker som konsulent for Laboratoriet for Fundering, AUC.

Tidligere stillinger:

1970-74:	Projektingeniør, Forskningsafdelingen, Norges Geotekniske Institut.
1974-92:	Sektionsleder, Sektionen for Specielle Opgaver, Norges Geotekniske Institut.

Publikationsvirksomhed:

Forfatter til ca. 35 tidsskriftsartikler, kongresindlæg og rapporter inden for fundering, offshore konstruktioner, og cykliske belastning af jord.

CURRICULUM VITAE (resumé)

Navn:	Svend Ole Hansen
Fødselsdato:	1951
Nationalitet:	Dansk
Stilling:	Direktør (indehaver) Svend Ole Hansen ApS Sct. Jørgens Allé 7 DK-1615 København V
Uddannelse:	Civilingeniør, Danmarks Tekniske Højskole, 1975. Lic. Techn., Danmarks Tekniske Højskole, 1978.
Kvalifikationer:	(udvalg): S. O. Hansen ApS driver specialiseret konsulentvirksomhed inden for vindteknik, konstruktioners dynamiske og konstruktioners sikkerhed. Firmaet ejer og opererer en vindtunnel, der benyttes til forskning og konsulentarbejde. Alsidige konsulentopgaver for A/S Storebæltsforbindelsen, kraftværker, skorstensfabrikanter, Københavns Idrætspark, Dansk Standards Lastnormudvalg m.fl.

Tidligere stillinger:

1977-89:	Ekstern forelæser ved DtH vedrørende vindbelastninger.
1978-79:	Ingeniør, COWI-consult.
1979-81:	Forskningsingeniør, Forskningscenter Risø.
1981-87:	Sektionsleder, Skibsteknisk Laboratorium.

Publikationsvirksomhed:

Forfatter til bogen 'Vindlast på Bærende Konstruktioner' (med C. Dyrbye) fra 1989 samt ca. 15 artikler, kongresindlæg og rapporter, primært omhandlende vindlast på konstruktioner.

APPENDIX B

Centre for Dynamic Measurements

In 1990 the Danish Technical Research Council granted 5.2 mill. DKK (approximately $870.000) to 2 departments at Aalborg University, namely the Department of Civil Engineering and the Department of Building Technology and Structural Engineering.

The grant has been used to build up a Centre for Dynamic Measurements of Civil Engineering Structures and Building Materials including Soil, abbreviated Centre for Dynamic Measurements or simply CDM.

CDM has no laboratories of its own but forms an integral part of the usual laboratories for the 2 departments. 3 laboratories are thus a part of CDM and in this pamphlet a short description of these 3 laboratories is given.

The two departments now offer better facilities for measurements and analysis of many different structures exposed to dynamic loads such as wind loads, wave loads, earthquake loadings and traffic loads. Examples of such structures are offshore structures, masts, chimneys, bridges and high-rise buildings.

Another field of interest is the determination of the dynamic properties of building materials as for ... be determined by experimental methods only. This includes fatigue and fracture mechanics.
Some other subjects are system identification, vibration based inspection, development of data acquisition systems and analysis of experimental data from dynamic measurements.

CDM has the facilities to help consulting firms, manufacturers and other companies to solve problems within the field of dynamic loads, dynamic response of civil engineering structures, structural dynamics, soil dynamics, fatigue and fracture mechanics.

For further information of the Centre for Dynamic Measurements, please contact the 2 departments or the contact persons mentioned on the other pages of this pamphlet.

Department of Civil Engineering
Secretariat:
Ms Alice Larsen
Phone: +45 98154211 # 6507
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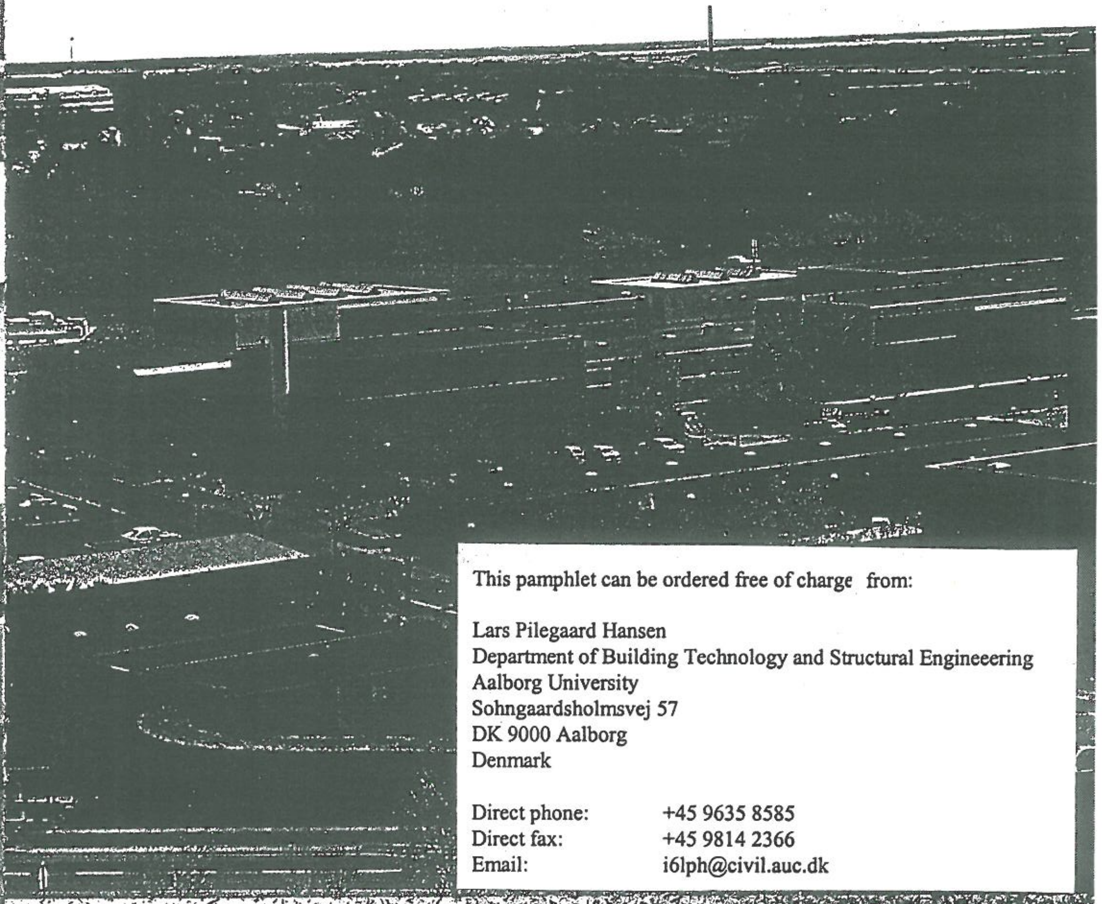
Email: i5al@civil.auc.dk

Department of Building Technology and Structural Engineering
Secretariat:
Ms Tove Jensen
Phone: +45 98154211 # 6621
Fax: +45 98148243
Email: i6tj@civil.auc.dk

Sohngaardsholmsvej 57,
DK- 9000 Aalborg, Denmark

Centre for Dynamic Measurements



This pamphlet can be ordered free of charge from:

Lars Pilegaard Hansen
Department of Building Technology and Structural Engineeering
Aalborg University
Sohngaardsholmsvej 57
DK 9000 Aalborg
Denmark

Direct phone: +45 9635 8585
Direct fax: +45 9814 2366
Email: i6lph@civil.auc.dk

AALBORG UNIVERSITY

Geotechnical Engineering Laboratory

Research Areas and Facilities
The research programme of the Geotechnical Engineering Group focuses on three main areas:

- Geotechnical design parameters
- Innovative foundation principles
- Environmental geotechnology

To support the research extensive laboratory facilities are available including state-of-the-art equipment for element and model testing of soil specimens ranging from tens of millemetres to metres.

The geotechnical laboratory consists of several dedicated laboratory testing rooms and a major 136 m² testing hall with strong floor.

Element Testing
The dedicated laboratories range from geotechnical and environmental classification testing to state-of-the-art static and dynamic element testing:

- Static or dynamic stress-strain controlled triaxial tests on cylindrical specimens. Diameters D = 42 mm, 70 mm and 250 mm.
- True triaxial testing on intact or reconstituted cubic specimens with side length from 50 to 70 mm.
- Bender element testing of elastic material properties and shear wave propagation implemented in: longitudinal-torsional resonant column device, G_{max} - Triaxial cell.
- Dynamic shear box for fatigue characterization.
- Directional shear box for testing of directional anisotropy.
- A range of oedometers (specimen diameters from 35 to 70 mm) from hydrostatic loading cells for very soft soils to very rugged Moust Jacobsen type oedometers for testing of high stiffness materials.
- High resolution sensors and fully automated data acquisitions and test control for strain and stress controlled testing.
- Permeameters for testing of hydraulic properties.

Model Testing
The strong floor allows all kinds of model set-ups with dimensions up to several metres due to extensive crane and handling facilities.

The current focus is on dynamic model testing. The set-up includes a steel box for testing of 1.6 x 1.6 x 0.65 m³ soil specimens which allows:

- Simulation of earthquakes
- Simulation of environmental loading on structures

For earthquake loading the box is raised on four airbags allowing the box to move freely in a horizontal plane. A major stand-alone hydraulic pumping station with a working pressure of 210 bars powers the set-up with three independent hydraulic actuators with:

- Maximum force of 100 kN
- Maximum displacement ± 25 mm
- Maximum frequency 25 to 40 Hz
- Maximum acceleration 3 g

The loading of the model set-up is controlled by an advanced electro-hydraulic control system consisting of a programmable servo control system.

Supplementary Equipment
The geotechnical laboratory is well equipped with a wide selection of actuators, sensors and data acquisition units for measurement of forces, displacements, pore pressures and accelerations. Field equipment for soil sampling, PDA measurements and settlement monitoring is available.

Further Iinformation
Further information on the research programme and services of the geotechnical engineering group may be obtained from:

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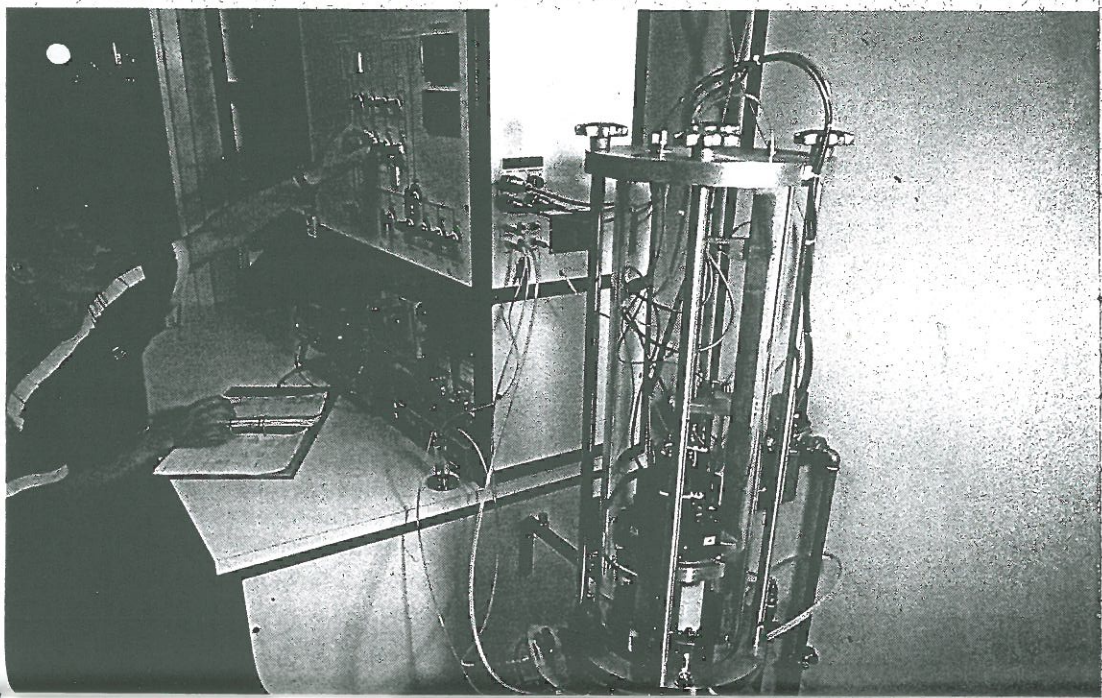
Fax: +45 98152555
Email: i5jst@civil.auc.dk



Equipment for longitudinal-torsional resonant column tests on soil.

Structural Research Laboratory

In the structural research laboratory equipment is available for performing static and dynamic tests on structures, structural members and building materials.

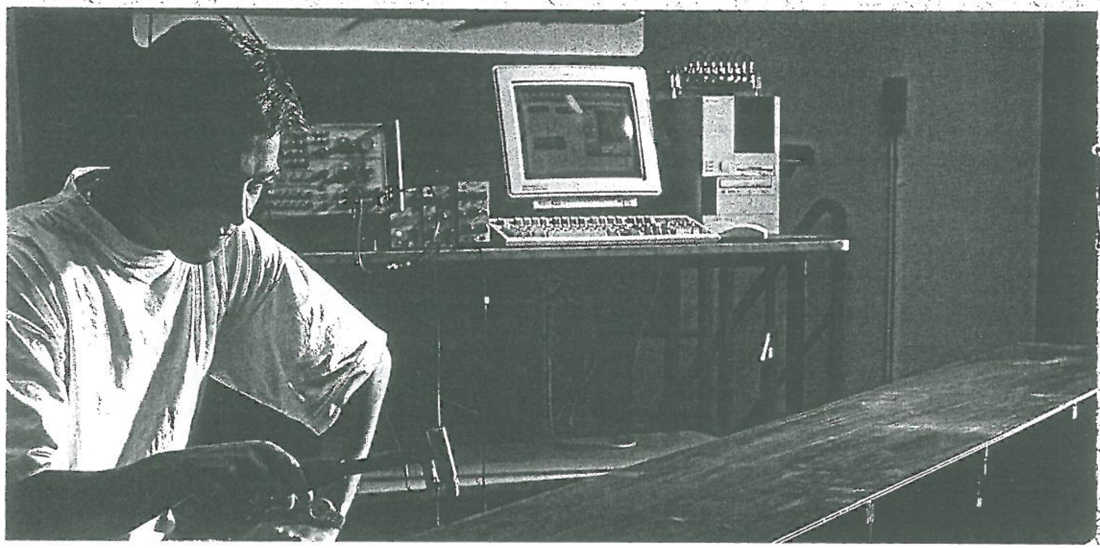
The laboratory has two strong floors, 136 m^2 and 70 m^2, on which loading arrangements can be set up. Up to 1000 kN load can be applied on the strong floors.

Actuators and Testing Machines
For producing time–varying loads the laboratory has 2 actuators of 63 kN and 250 kN, respectively, with corresponding load cells. These are, together with a testing machine, see below, included in a HYDROPULS plant consisting of hydraulic equipment with cooler, control unit and microcomputer. The plant facilitates the generation of deterministic and stochastic signals.

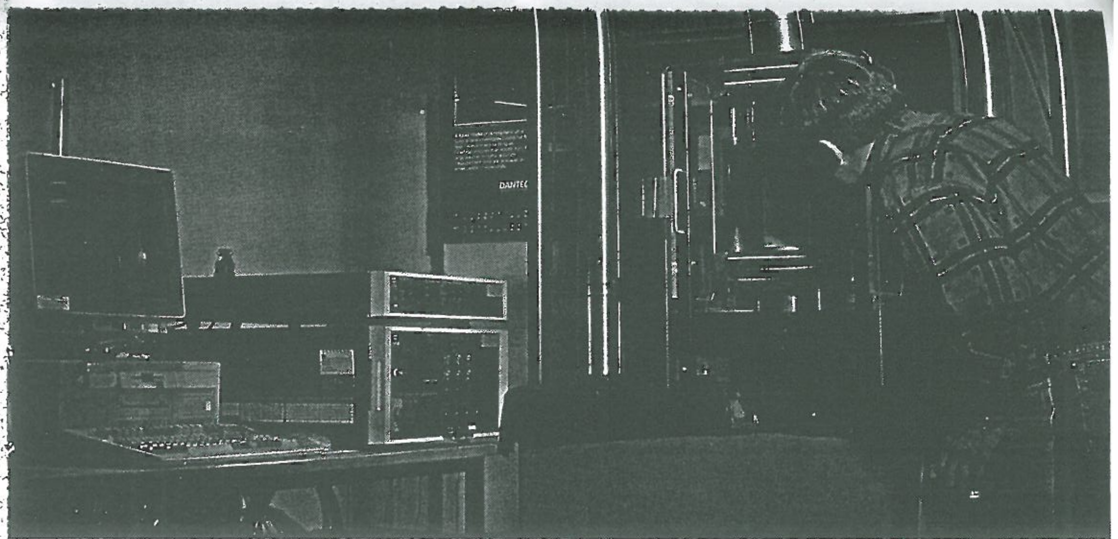
To create minor time-varying loads the laboratory has an electrodynamic vibration actuator with control systems for sinusoidal loads.

The laboratory has several testing machines and some are mentioned here:

- 600 kN hydraulic universal testing machine (Mohr and Federhaff).
- 500 kN dynamic loading frame with electronic control. PC-controlled (MTS).
- 250 kN dynamic loading frame with electronic control. Micro computer controlled. (Schenck).
- 50 kN dynamic loading frame with electronic control. (Our own make).



Dynamic test in laboratory on model of highway bridge.



500 kN dynamic loading frame with electronic control.

Equipment for Load and Response Measurements
For measuring loads and responses (displacements, accelerations, strains, etc.) the laboratory has several load cells, electronic (inductive) displacement transducers (LVDT's) with measurement amplifiers, different types of accelerometers both for laboratory and in situ measurements and strain gauge equipment.

Equipment for Data Acquisition
For data acquisition in connection with dynamic simultaneous measurements the laboratory has 3 data acquisition systems (12, 12 and 16 channels). The maximum sampling rate is 9600Hz. In addition, several personal computers are provided with data acquisition cards. Data recording can also be carried out with tape recorders and the labora-tory has one 14 channel and three 4 channel FM tape recorders. In connection with modal analysis and other dynamic tests the laboratory has two frequency analysers and a modal analysis system (STAR).

Supplementary Equipment
Furthermore, the laboratory has various measuring, recording and auxiliary equipment such as storage oscilloscopes, function generators, filters, phase meter, calibration equipment and x–y–recorders. For wind measurements, two wind velocity meters and two wind direction meters are available.

Further Information
For further information on the laboratory and the research and development tasks accomplished in the years, please contact:

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The Hydraulics and Coastal Engineering Laboratory

The laboratory covers hydrodynamics, hydrology, hydraulics, coastal and offshore engineering. The research of this laboratory presently focuses on:

- development of wave generation hard- and software
- analysis of wind generated waves
- wave disturbance in harbours
- loads on coastal and offshore structures
- hydraulic and structural integrity stability of breakwater armour units
- stability of caisson structures
- reliability evaluation of coastal structures
- dilution and dispersion in the coastal zone
- cohesive sediment transport
- stormwater run-off for urban catchment areas.

Basic tools are physical and numerical modelling and field measurements. The laboratory has:

- 2 multi directional wave basins
- 5 waves and current flumes
- advanced measuring equipment for determination of hydraulic loads.

In addition, PC based software for registration and analysis of measured signals is available.

Examples of structures which can be examined for dynamic loads and responses are:
Pillars, oil platforms, pier structures, and breakwaters.

Further Information
Further information of the laboratory and the research and ser-vices of the hydraulics engineering group may be obtained from:

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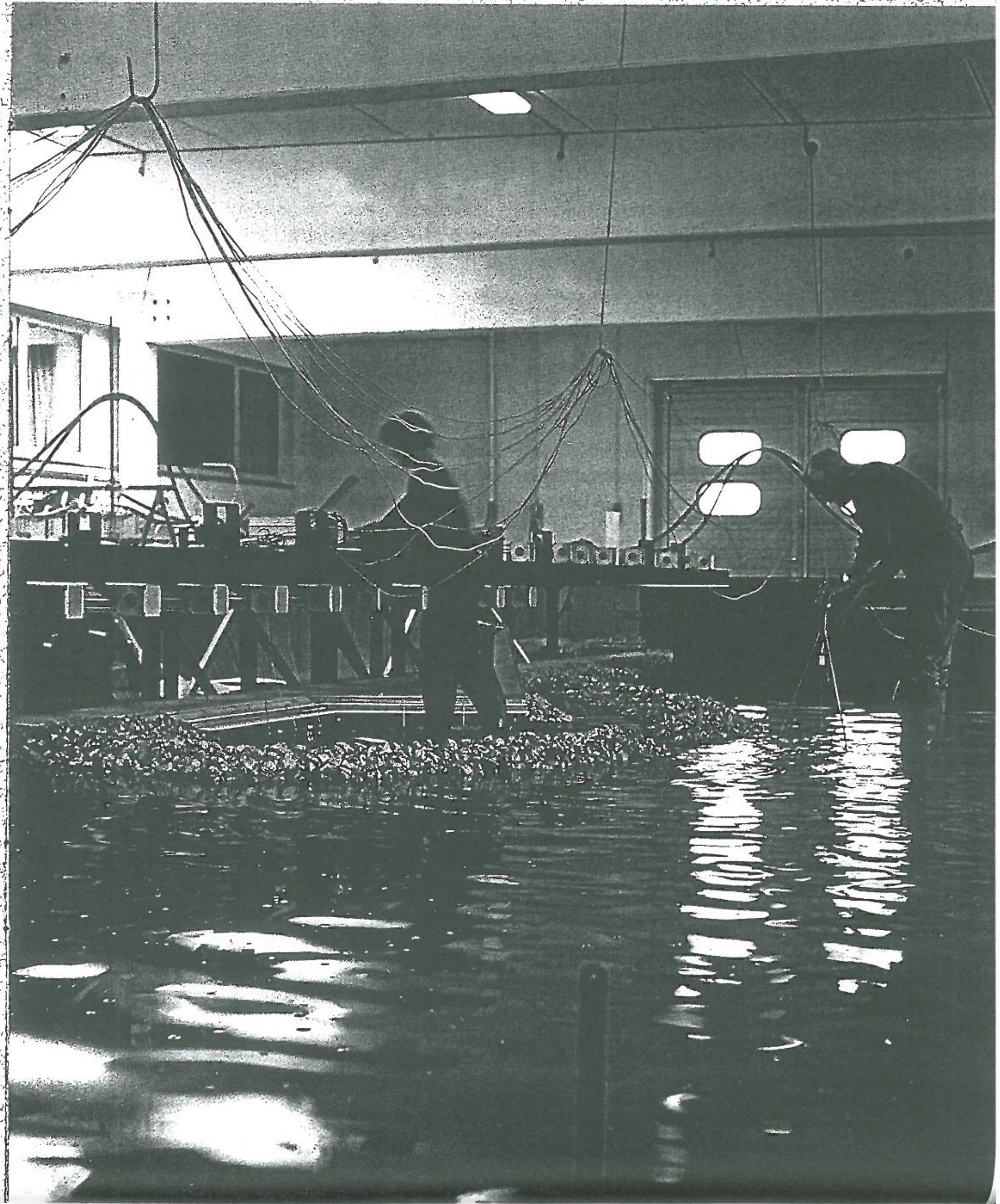
Wave basin with model test of breakwater extension of the »Kattegat Center« in Grenaa.



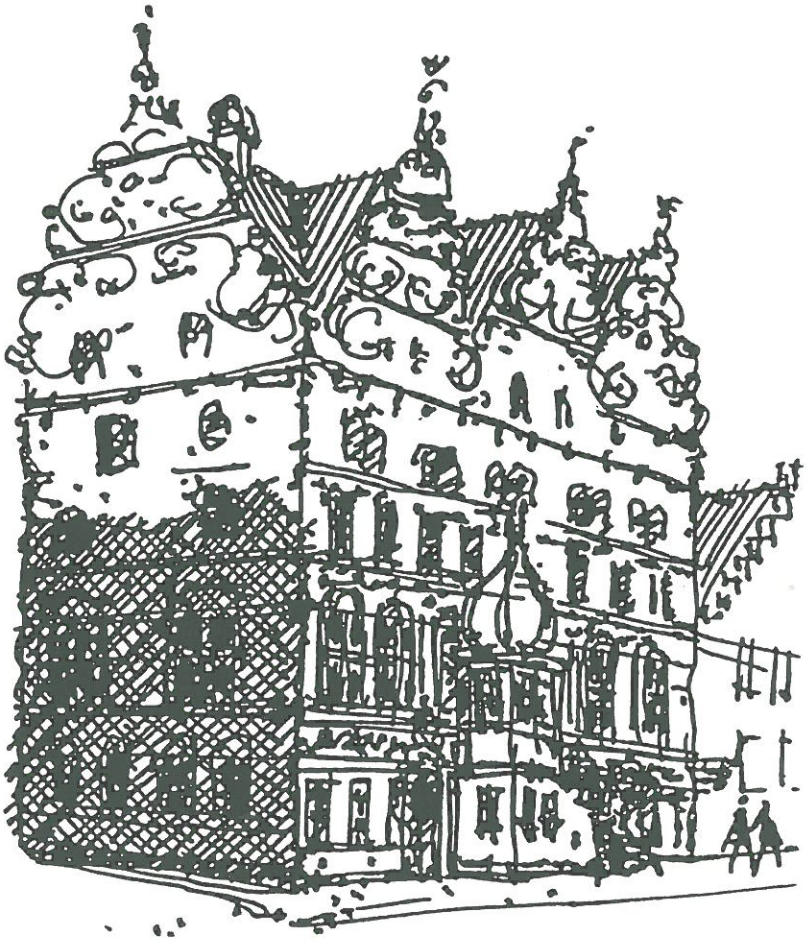
APPENDIX C

Workshop, September 14 - 15, 1994

DYNAMICS OF STRUCTURES

A workshop on dynamic loads and
response of structures and soil dynamics

AALBORG UNIVERSITY
DENMARK
September 14-15, 1994



DYNAMICS OF STRUCTURES

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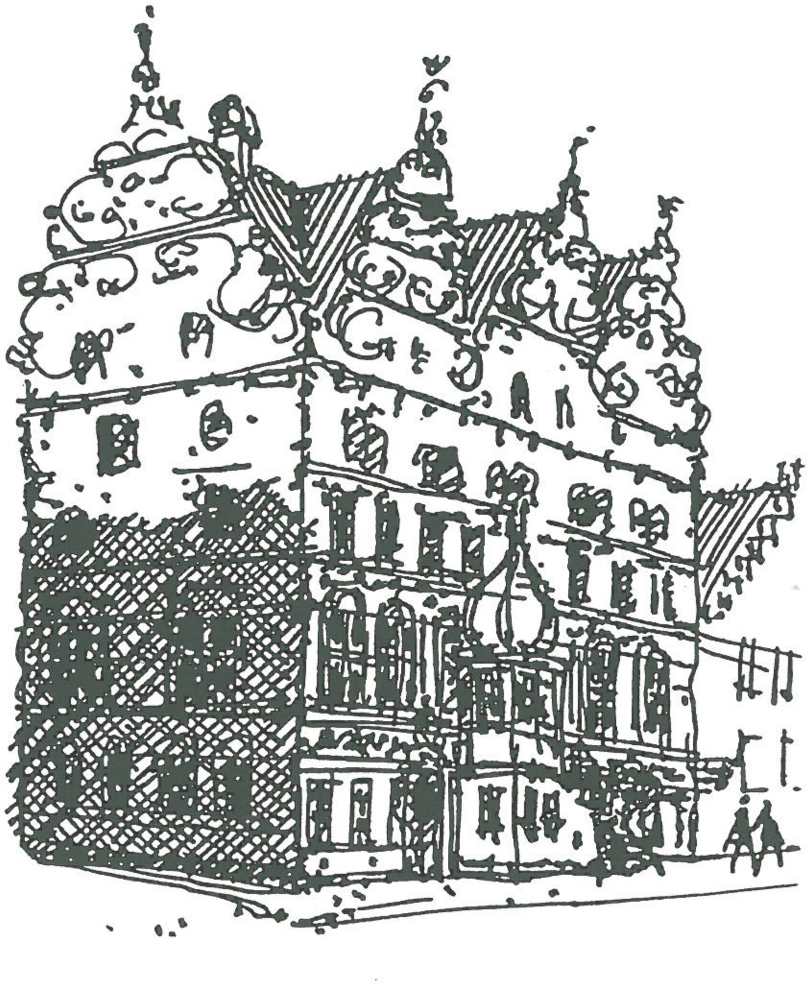

Dynamics of Structures,

Workshop Programme

Wednesday, September 14, Lecture Room A217

15.00-17.00	Presentation of laboratories and tests: *Structural Lab.:* Damage detection and fatigue. *Geotechnical Lab.:* Dynamic triaxial tests. *Hydraulics Lab.:* Dynamic wave loads.
19.30-?	**Dinner at restaurant Kniv & Gaffel, Maren Turisgade 10, 9000 Aalborg.**

Thursday, September 15, Lecture Room A217

09.00-09.05	**Welcome by Steen Krenk, Aalborg University**
09.00-09.30	*Lessons from Model Tests with Cyclic Loading of a Gravity Structure on Very Dense Sand,* Knut Andersen, Norwegian Geotechnical Institute
09.30-09.45	*Simplified Response Analysis of Guyed Masts according to EC3 Part 3.1,* Mogens G. Nielsen, Rambøll, Hannemann & Højlund A/S
09.45-10.00	*A Non-Linear Mathematical Model For Vortes Shedding Forces On Flexible Structures*, Allan Larsen, COWIconsult A/S
10.00-10.15	*Identification and Damage Detection on Structural Systems*, Rune Brincker, Aalborg University
10.15-10.30	*Damage Assessment of a Steel Lattice Mast under Natural Excitation,* Poul Henning Kirkegaard, Aalborg University
10.30-11.00	**Coffee**
11.00.11.30	*Dynamic Problems Related to Coastal Structures,* Hans Falk Burcharth, Aalborg University
11.30-11.45	*Development of Pore Pressure and Material Damping during Cyclic Loading,* Lars Bo Ibsen, Aalborg University
11.45-12.00	*Linear and Quadratic Lanczos Algorithms*, Steffen Vissing, Aalborg University
12.00-12.15	*Prediction of Global and Localized Damage and Future Reliability for RC Structures Subject to Earthquakes,* Søren R.K. Nielsen, Aalborg University
12.15-12.30	*Perturbation Solutions for Random Linear Structural Systems Subject to Random Excitation using Stochastic Differential Equations,* Søren R.K. Nielsen, Aalborg University
12.30-13.30	**Lunch**
13.30-14.00	*Measured and Predicted Response of an Offshore Gravity Platform,* Ivar Langen, Høgskolesenteret i Rogaland, Norway
14.00-14.30	*Dynamic Aspects of Bridge Piers with Plane Base Plate*, Helge Gravesen/Ole A. Madsen, Carl Bro Civil and Transportation A/S
14.30-14.45	*Man-Induced Vibrations*, Jeppe Jönsson, Aalborg University
14.45-15.00	*Fatigue and Crack Propagation*, Thomas Cornelius Hansen, Danish Technical University
15.00	**Closure**

Workshop, den 14.-15. september 1994
Aalborg Universitet

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LESSONS FROM MODEL TESTS WITH CYCLIC LOADING OF A GRAVITY STRUCTURE ON VERY DENSE SAND

by

Knut H. Andersen, Norwegian Geotechnical Institute

Model testing has in the past been successfully used to verify the foundation design procedures for cyclically loaded structures on clay. Model testing of cyclically loaded structures on sand has been limited, however, and the foundation design procedures for cyclically loaded structures on sand have not been verified to the same extent as for structures on clay.

The main reasons why model testing of cyclically loaded structures on sand has been limited, are the needs to simulate the gravity stresses and the drainage conditions in the prototype correctly in the model. The gravity stresses can be modelled in centrifuge tests, but the drainage will occur much more rapidly in a centrifuge model than in a prototype. Pore pressure generation due to cyclic loading and negative pore pressures due to dilatancy are then not reproduced correctly.

Recently Delft Geotechnics developed a viscous fluid that can be used as pore fluid in various types of soil instead of water. This pore fluid enables scaling according to the similitude equations that must be fulfilled to perform realistic centrifuge model experiments of cyclically loaded structures on sand. Special triaxial and oedometer tests were run to show that the viscous pore fluid does not influence the engineering properties of the sand.

In a cooperative project between Delft Geotechnics and the Norwegian Geotechnical Institute, two pilot model tests were performed on an offshore gravity platform on very dense sand to demonstrate the feasibility of the centrifuge modelling technique with the new pore fluid. In one test the platform was loaded monotonically, and in the other test it was loaded with a cyclic load history representative for a North Sea design storm. The tests were instrumented with piezometers and total stress devices at the base. Displacement transducers defined all displacement components, and a load cell attached to the hydraulic actuator recorded the applied loading history.

Even if these first tests were meant as pilot tests to demonstrate the feasibility of the centrifuge modelling technique, they provided valuable

DYNAMICS OF STRUCTURES
Aalborg University, Denmark, September 14-15, 1994.

SIMPLIFIED RESPONSE ANALYSIS OF GUYED MASTS ACCORDING TO EC3 PART 3.1

Mogens G. Nielsen
Rambøll, Hannemann & Højlund A/S
Bredevej 2, DK-2830 Virum, Denmark.

1. INTRODUCTION

The response of a guyed mast is rather difficult to analyze due to the non-linearities of the structure and the dynamics of the wind.

Guyed masts differs from towers by having non-linear deflections and several low eigenfrequencies, which makes the stochastic analysis very extensive.

Over the history a lot of different methods has been used for analysing guyed masts in order to make a simplified model of the dynamic response. Some of the methods is described below.

At the present time work is being done to make an European code for towers and masts: EUROCODE 3: Part 3.1 [2] and Rambøll, Hannemann & Højlund participates in this work.

2. ANALYSIS ACCORDING TO THE IASS-RECOMMENDATION

The method proposed in the IASS-recommendation for guyed masts [1] is based on patch wind loading in order to model the dynamics of the wind.

The principle of the method is to find the worst combination of the response from varying the wind pressure in some patches over the height of the guyed mast between the mean wind pressure and the maximum wind pressure. The maximum wind pressure is equal to the gust wind pressure except for the cantilever part where it is the gust wind pressure increased by 30%.

The patches are based on the spans between adjacent guy levels and over the cantilever if any. The procedure requires several static wind analyses for each wind direction considered in order to get the maximum response.

3. ANALYSIS ACCORDING TO THE RH&H PROCEDURE

Rambøll, Hannemann & Højlund has designed guyed masts for almost 50 years and has introduced a new patch wind method which in principle is as the procedure in

A Non-Linear Mathematical Model For Vortex Shedding Forces On Flexible Structures

Allan Larsen
COWIconsult A/S, Parallelvej 15, 2800 Lyngby, Denmark

Abstract

The present paper (condensed form) proposes a one degree of freedom (1DOF) non-linear model of self limiting cyclic fluid loads for application in Finite Element Method analyses of light flexible structures subjected to vortex shedding excitation under lock-in conditions. Being empirical by nature, the model includes three independent parameters to be determined from response tests with representative fluid-elastic scale models or prototypes. The presentation will evaluate the proposed load / response model against other 1DOF empirical vortex shedding models which have found some acceptance in structural engineering and will discuss methods for parameter identification from measured response data.

1. INTRODUCTION

Flexible and lightly damped slender structures are often found to be prone to vortex-induced vibrations when submerged in a stream of fluid. Notable examples includes cable supported bridges, chimneys and towers exposed to wind and marine risers, pipelines, poles and taut cables exposed to ocean current. The bluff shape of most practical structural cross sections promotes formation of periodic and coherent von Karman type "vortex streets" in the wake of the structure. Large amplitude resonant vibrations may occur in speed ranges of the fluid flow where the vortex shedding action locks on to one of the cross flow vibration modes of the structure. At this condition, commonly referred to as lock-in, vortex-induced vibrations are found to be self-limiting, amplitude dependent and highly sensitive to the density of the fluid and the mass density and the inherent damping level of the structure.

The Finite Element Method has received broad acceptance as the foremost analysis tool in contemporary structural engineering. FEM analyses allow detailed computations of the overall response and stress distributions in critical structural members subjected to deterministic or random loads. Hence FEM computations appear as the logical choice for assessment of vortex shedding action on slender structures and for evaluation of alternative damping measures intended for suppression of excessive vortex induced responses.

The objective of the present paper is to establish a suitable forcing function model which recognizes the non-linear amplitude dependent character of the vortex shedding action. Also the model must be capable of reproducing the functional relationship between response and mass density / structural damping as estab-

IDENTIFICATION AND DAMAGE DETECTION ON STRUCTURAL SYSTEMS

Rune Brincker, Associate Professor of Civil Engineering
Poul Henning Kirkegaard, Assistent Professor of Experimental Mechanics
Palle Andersen, Ph.D.-student
University of Aalborg

Abstract

A short introduction is given to system idenfication and damage assessment in civil engineering structures. The most commonly used FFT-based techniques for system identification are mentioned, and the Random decrement technique and parametric methods based on ARMA models are introduced. Speed and accuracy are discussed. Finally some commenly used damage indicators are mentioned, and the problem of identifying damage from a set of damage indicators is discussed.

Identification from dynamical response

Identification of physical properties from the dynamic response of structural systems - often called experimental modal analysis or system identification - is an area where a huge amount of research has been carried out, and where the interest for research results and practical applications is still increasing.

The growing interest for these techniques can be explained in different ways. One explanation is that computational possibilities in structural dynamics are getting better and new structural designs are introduced calling for a better and more detailed knowledge about the physical properties of the structures and how these properties are affected by damage and changes in load conditions. Another explanation is that by introduction of the computer in the measurement system, the possibility of handling large amounts of data became available, and the potential of the techniques were revealed.

The many possibilities of practical applications can be illustrated by studying one of the latest conference proceedings about experimental modal analysis, for instance one of the latest IMAC proceedings, see [15]. Only a few examples of applications will be mentioned here.

One of the first applications of structural dynamic measurement was in the 1940's where the problem of describing the loads on aircraft wings was studied and where especially the problems of flutter gave rise to experimental studies of the dynamical properties of aircraft

Damage Assessment of a Steel Lattice Mast under Natural Excitation

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A. Rytter

Applied Mechanics Unit, Ispra, Italy

Abstract: In this paper the possibility of detecting and locating damages in a 20 m high steel lattice mast subjected to natural excitation has been investigated. For the damaged mast seven different damage states were considered. In these damage states a damage was assumed in one of the lower diagonals. These diagonals were cut and provided with a bolted joint implying that a damage could be simulated. Based on 20 periodical measurements during 6 months the sensitivity of the modal parameters, identified by an ARMA-model, to environmental conditions such as wind-direction, wind-speed and air-temperature have been investigated. These sensitivities have been compared with the changes of modal parameters due to a damage. It is found that the measured natural frequencies vary less than one per cent while the measured modal damping ratios vary more than twenty per cent due to different environmental conditions. The measured bending natural frequencies and the measured rotational frequency approximately decrease few per cent and more than ten per cents, respectively, due to a damage corresponding to a removal of one of the lower diagonals. The results also show that a neural network trained with simulated data is capable for detecting location of a damage in the steel lattice mast when the network is subjected to the experimental data.

Keywords. System identification, ARMA-model, damage detection, civil engineering application, neural networks.

1. Introduction

Structural diagnosis by measuring vibrational signals of civil engineering structures is a subject of research which has received increasing interest during the last decades. The main impetus for doing vibrational based inspection (VBI) is caused by a wish to establish an alternative damage assessment method to the more traditionally methods such as e.g. visual inspection. Many research projects have concluded that it is possible to detect damages in civil engineering structures by VBI, and some techniques to locate damages in civil engineering structures have also been proposed. However, much of the performed research has been based on numerical simulations and on laboratory models. A throughout review of VBI techniques can be found in Rytter [1].

In order to use VBI techniques it is necessary to be able to obtain reliable estimates of the dynamic characteristics, e.g. natural frequencies. Such quantities can be estimated from the resulting output caused by a known well-defined input. However, the estimates can also be estimated by using the so-called ambient testing, i.e. the only excitation on the structure is the natural excitation.

The aim of the research presented in this paper was to answer the following questions by using full-scale measurements based on natural excitation:

Dynamic Response of Breakwaters

by

Hans Falk Burcharth

Wind generated storm waves cause dynamic loads on breakwaters. The problems related to the structural response depend on the type of structure. In case of monolithic structures, like sandfilled concrete caissons, the problems are associated with the overall stability of the monolith and not with the structural members, i.e. the front plate of the caisson. In case of rubble mound structures the problems are related to the integrity of the slender types of concrete armour units, and to the stability of super structures (parapet walls), if present.

The presentation will discuss the present stage of knowledge associated with the problems of designing breakwater structures. For the case of rubble mound structures a method of designing armour layers made of slender unreinforced concrete units has been developed. For the other cases no saticfactory methods exist so far but research is ongoing.

Development of pore pressure and material damping during cyclic loading

L.B. Ibsen, Aalborg University, Denmark

ABSTRACT: The behaviour of sand during cyclic loading can be characterized as "stabilization", "instant stabilization", "pore pressure buildup" and "liquefaction". The terminologies can be defined exactly by a simple mathematical formulation based on the existence of a cyclic stable state. By introducing a mobilization index M it is possible to describe the strongly hysteretic behaviour during loading and unloading, even if the stress path is complicated.

INTRODUCTION

In the last thirty years a great number of test series with cyclic loading of sand have been performed, many phenomena have been described and important theories have been presented. Today the main problem is to gather all relevant information in a consistent mathematical formulation.

Laboratory testing gives a possibility to study soil behaviour in details. However, it is widely recognized that it is not possible to use laboratory test results for practical purposes without calibrating them against field tests and field observations.

For instance, the preparation of a sand specimen and the reconstruction of stress history and seismic history have a major effect on the cyclic behaviour. In most natural deposits, soil elements are subjected to shear stresses corresponding to the "earth pressure of rest" situation. In earth structures close to natural slopes or beneath foundations, soil elements are subjected to even larger shear stresses. The stress history is reconstructed by anisotropic consolidation before cyclic testing.

An old sand deposit in an earthquake region has been vibrated many times in its lifetime and the specimen should therefore be prepared by a vibration technique at a level corresponding to the seismic history.

The success of laboratory testing depends on the extent to which the in-situ characteristics are reestablished.

The purpose of this paper is therefore limited to describe in mathematical formulations the phenomena involved in soil response on cyclic loading, and to give a definition of the terminologies, which are already accepted, but not clearly defined. It combines the two different assumptions

i) Alternating loads build up pore pressure, and liquefaction will develop if the amplitude or the number of cycles are big enough (initiated by Seed and Lee in 1966).

ii) The initial effective stress state and the relative density of the soil play a definitive role for the behaviour of a soil. If the initial shear stress exceeds a certain value the pore pressure will be reduced by cyclic loading and the soil will stabilize (Casagrande 1976, Castro and Poulus 1977, Loung 1980).

The paper is based on triaxial tests on a uniform sand called Lund no 0. The mean diameter $d_{50} = 0.4\ mm$, the coefficient of uniformity $U = 1.7$, the initial void ratio 0.62 corresponding to a density index $I_D = 0.7$. The test specimens were prepared by a pluvial technique and carefully saturated in vacuum. A test consists of an anisotropic consolidation phase followed by cyclic loading at constant volume.

STATIC BEHAVIOUR OF DENSE SAND

The parameters, which describe the state of a soil under axisymmetrical stress conditions, are

$$\begin{aligned}
&\text{the mean normal stress} & p' &= \frac{1}{3}(\sigma_1' + 2\sigma_3') \\
&\text{the deviator stress} & q' &= (\sigma_1' - \sigma_3') \\
&\text{the volumetric strain} & \varepsilon_v &= \varepsilon_1 + 2\varepsilon_3 \\
&\text{the distorsion} & \varepsilon_q &= \frac{2}{3}(\varepsilon_1 - \varepsilon_3)
\end{aligned} \qquad (1)$$

where σ_1 is the vertical and σ_3 the horizontal pressure.

The strength of a soil is normally described by the Mohr-Coulomb's failure criterion. "Failure" is defined as a state where q is maximum, and corresponds normally to a distorsion $\varepsilon_q = 5 - 10\%$. The strength parameters c' and φ' are assumed to depend on the void ratio only. In Figure 1 is shown the failure line corresponding to $e = 0.62$.

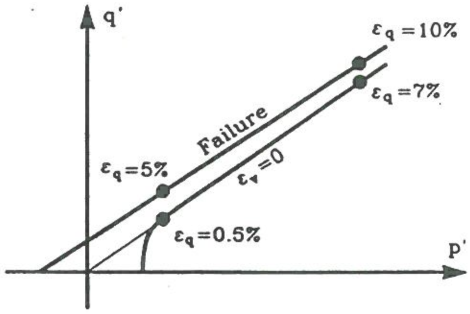

Figure 1. Stress path in an undrained test compared with the Mohr-Coulomb failure criterion.

Linear and Quadratic Lanczos Algorithms

Steffen Vissing & Steen Krenk
Department of Building Technology and Structural Engineering
Aalborg University, DK–9000 Aalborg, Denmark

Eigenvalue problems arise in various engineering problems as for instance structural dynamics and stability analysis as well as in heat tranfer analysis. The solution of linear or quadratic eigenvalue problems is therefore an essentiel part of the analysis. Quadratic eigenvalue problems are often solved after reduction to an indefinite linear eigenvalue problem of double size and thus the fundamental problem is the generalized indefinite linear eigenvalue problem. In this paper Lanczos algorithms for the symmetric problem is developed, but the algorithms may be generalized to nonsymmetric problems by introducing biorthogonal sets of left and right vectors. The generalized linear eigenvalue problem is of the form

$$(\mathbf{A} + \lambda\mathbf{B})\mathbf{w} = \mathbf{0} \tag{1}$$

where $\mathbf{A}$ and $\mathbf{B}$ are $n \times n$ real symmetric matrices which may be indefinite, λ is an eigenvalue and $\mathbf{w}$ is the corresponding n-dimensional eigenvector.

A general strategy for the generalized linear indefinite eigenvalue problem (1) consists of setting up a Krylov sequence representing the required eigenvectors and defining a proper orthogonality condition and vector orientation. A Krylov subspace suitable for approximate representation of the eigenvectors corresponding to the numerically smallest or largest eigenvalues can be generated by iterating with the matrix $\mathbf{A}^{-1}\mathbf{B}$ or the matrix $\mathbf{B}^{-1}\mathbf{A}$. The eigenvalue problem may typically arise from a finite element formulation in which the discretization causes the largest errors for the numerically largest eigenvalues. Further more only a small fraction of the eigenvectors corresponding to the numerically smallest eigenvalues may approximate a response to sufficient accuracy. Therefore the following Krylov sequence is used

$$[\mathbf{w}_0,\ \mathbf{A}^{-1}\mathbf{B}\mathbf{w}_0,\ (\mathbf{A}^{-1}\mathbf{B})^2\mathbf{w}_0, \ldots,\ (\mathbf{A}^{-1}\mathbf{B})^{m-1}\mathbf{w}_0] \tag{2}$$

However, an efficient use of the Krylov sequence requires some kind of condition on the base vectors, e.g. a suitable orthogonality condition. Natural choices for orthogonalizing the Krylov vectors are either of the two system matrices $\mathbf{A}$ and $\mathbf{B}$ or a simple matrix like the identity matrix. This paper presents algorithms in which the vectors are orthogonalized with respect to either of the system matrices. Hereby the vectors need in principle only be orthogonalized to the previous two vectors in order to achieve orthogonality and only two parameters in the recurrence formulae are needed. However, in finite precision the numerical error increase in each iteration whereby non-orthogonal vectors may be generated. In order to prevent the loss of orthogonality a simple reorthogonalisation procedure is applied. Using either $\mathbf{A}$ or $\mathbf{B}$ orthogonality conditions the n-dimensional eigenvalue

PREDICTION OF GLOBAL AND LOCALIZED DAMAGE AND FUTURE RELIABILITY FOR RC STRUCTURES SUBJECT TO EARTHQUAKES

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A.Ş. Çakmak
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P.H. Kirkegaard
Department of Building Technology and Structural Engineering, Aalborg University, Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark

SUMMARY

The paper deals with the prediction of global and localized damage and the future reliability estimation of partly damaged reinforced concrete (RC) structures under seismic excitation. Initially, a global maximum softening damage indicator is considered based on the variation of the eigenfrequency of the first mode due to the stiffness and strength deterioration of the structure. The hysteresis of the first mode is modelled by a Clough and Johnston hysteretic oscillator [1] with a degrading elastic fraction of the restoring force. The linear parameters of the model are assumed to be known, measured before the arrival of the first earthquake from non-destructive vibration tests or via structural analysis. The previous excitation and displacement response time series is employed for the identification of the instantaneous softening using an ARMA model. The hysteresis parameters are updated after each earthquake. The proposed model is next generalized for the MDOF system. Using the adapted models for the structure and the global damage state, the global damage in a future earthquake can then be estimated when a suitable earthquake model is applied. The performance of the model is illustrated on RC frames which were tested by Sözen and his associates [2,4].

1. INTRODUCTION

The physical local damage in reinforced concrete (RC) structures subject to severe seismic excitation is attributed to micro-cracking and crushing of concrete, yielding of the reinforcement bars and bond deterioration at the steel-concrete interfaces. To the extent

PERTURBATION SOLUTIONS FOR RANDOM LINEAR STRUCTURAL SYSTEMS SUBJECT TO RANDOM EXCITATION USING STOCHASTIC DIFFERENTIAL EQUATIONS

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SUMMARY

The paper deals with the first and second order statistical moments of the response of linear systems with random parameters subject to random excitation modelled as white-noise multiplied by an envelope function with random parameters. The method of analysis is basically a second order perturbation method using stochastic differential equations. The joint statistical moments entering the perturbation solution are determined by considering an augmented dynamic system with state variables made up of the displacement and velocity vector and their first and second derivatives with respect to the random parameters of the problem. Equations for partial derivatives are obtained from the partial differentiation of the equations of motion. The zero time-lag joint statistical moment equations for the augmented state vector are derived from the Itô differential formula. General formulation is given for multi-degree-of-freedom (MDOF) systems and the method is illustrated for a single-degree-of-freedom (SDOF) oscillator. The results are compared to those of exact results for a random oscillator subject to white noise excitation with random intensity.

1. INTRODUCTION

Structural uncertainties due to physical imperfections, model inaccuracies and system complexities are spatially distributed over the structure and can be mathematically modelled using either random variables or random processes which may be functions of time and/or space. The uncertainty of the structural model parameters and of the excitation parameters may induce uncertainty in the system response of the same magnitude as the random dynamic loads, and should therefore be included in the analysis. In the 1980s, the analysis of the response variability of stochastic structural systems

MEASURED AND PREDICTED DYNAMIC BEHAVIOUR OF AN OFFSHORE GRAVITY PLATFORM

by

Ivar Langen, Høgskolen i Stavanger, Stavanger, Norway

EXTENDED ABSTRACT

The Gullfaks C platform which was installed in May 1989 on 217 metres water depth in the North Sea, is the largest offshore gravity base concrete structure in the world up to now. The general layout of thew platform is given in Figure 1. This huge platform is furthermore placed on a site with multilayered soft and geotechnically complex soil conditions. To obtain necessary stability and bearing capacity a new foundation solution was introduced with circular concrete skirts penetrating 22 metres into the soil and with a drainage system by which consolidation of the soil can be accelerated and controlled.

On this background a comprehensive foundation and structure monitoring system was installed including 207 sensors which measure environmental conditions, structural behaviour and foundation behaviour. The purpose of the instrumentation was both design verification and short and long term monitoring of the platform.The instrumentation system is summarized in Figure 2.

This paper discusses the measured dynamic behaviour of the platform. The foundation behaviour and special features of the instrumentation is covered in papers by Tjelta and al. [1] and Myrvoll [2]. Two subjects are emphasized: Identification of a dynamic model of the platform and a discussion of the dynamic response.

In the identification procedure both natural frequencies and mode shapes are used. These and the damping are estimated from the measurements using a multichannel ARMA model [3,4]. The first natural period is 3.01 sec and the damping ratio 1.4 - 2. The dynamic model as shown in Figure 3 is based on the design dynamic model and as built documentation. Uncertain parameters in this model as foundation spring stiffness, modulus of elasticity for concrete, deck stiffness and added mass are varied to obtain fit with the natural frequencies and mode shapes from the measurements. The identified model is furthermore compared with the design model, and predicted response obtained in the frequency domain using the model and a theoretical load model, is compared with measured response.

In the discussion of the measured dynamic response the paper features response composition, the probabilistic nature of the response, and possible nonlinearities in the soil structure interaction and wave loading. Special attention is given to observed ringing response in the platform.

As an example the wave and response spectral density in the highest seastate measured (H_s= 13.6, T_p =16.7) are shown in Figure 4. The response is mainly quasistatic. The resonance contribution to standard deviation is very small. Time series and polar plots of displacements are shown in Figure 5 and 6; both total response and response bandpass filtered at 0.25 Hz to give the wave frequency part and the resonant part. Of special interest is the resonant part which show transient

Paper for WORKSHOP "DYNAMICS OF STRUCTURES", AUC sept 14-15, 1994 HG/OAM

01.09.1994

DYNAMIC ASPECTS OF BRIDGE PIERS WITH PLANE BASE PLATE

by

Helge Gravesen and Ole A. Madsen, Carl Bro Civil and Transportation a/s

List of contents:

Abstract:

The paper summarizes some important experienced obtained from the West Bridge in the Storebælt Link. The alternative of the Contractor (ESG) included bridge piers with a plane base of reinforced concrete instead of open bottom caissons with in-situ casting of tremie concrete. The design change gives rise to a number of special requirements.

The paper includes first a review of the major dynamic loads of importance for the bridge piers (ultimate and accidental loads). Then the requirements to and the experiences with the stonebed under the caisson bottom are reviewed. Next the consequences in terms of base plate design are reviewed. Finally, because of problem experienced with some valves in the bottom plate to be used in connection with placing the caissons on the stonebeds, the consequences for the bearing capacity of sandfilling the stonebed are reviewed.

The problems associated with the filter criteria between stone bed and soil and the consequences of sandfilling of the stonebed are the same for the alternative caissons considered.

Man-Induced Vibrations

J. Jönsson and L. Pilegaard Hansen
Department of Building Technology and Structural Engineering,
Aalborg University, Sohngaardsholmsvej 57, 9000 Aalborg, Denmark

Introduction

Human motion can cause various types of periodic or transient dynamic loads. The periodic loads are mainly due to jumping, running, dancing, walking and body rocking. Transient loads primarily result from single impulse loads, such as jumping and falling from elevated positions. The response to these loads are of primary interest for the structural engineer, whereas the exact load as a function of time generally is of minor importance. This is true when the loading time (contact duration) t_p is small compared to the largest natural periods $T_n = 2\pi/\omega_n$ of the structure. The present study is mainly concerned with spectator-induced vertical vibrations on grandstands. The idea is to use impulse response analysis and base the load description on the load impulse. If the method is feasable, it could be used in connection with the formulation of requirements in building codes.

During the last two decades work has been done on the measurement of the exact load functions and related reponse analysis. A recent work using a spectral description has been performed by Per-Erik Erikson [9] and includes a good literature survey. Bachmann and Ammann [1] give a good overview of vibrations caused by human activity. Other relevante references have been included in the reference list.

Periodic motion

The forces acting on a human body performing periodic motion can be decomposed in several ways. In this section the vertical motion is considered. A body shown in figure 1 (left) with mass m is acted upon by a gravitation force $F_g = mg$, a constant reaction force $F_c = \gamma mg$ and a dynamic force F_d. The constant reaction force F_c exists, if the body is in continous contact with a structure and it is the

Abstract

Fatigue and crack propagation

Thomas Cornelius Hansen

Fatigue crack propagation is a well-known phenomena. Normally it is studied by using empirical formulas. However at the Department of Structural Engineering, Technical University of Denmark, an energy balance crack growth formula has recently been developed **[90.1]**. This formula can be used to predict crack propagation arising both from static load and from fatigue loading.
The potential power of a theoretical formula is that it is not necessary to determine crack growth parameters by time demanding and expensive tests, as is the case when the well-known Paris equation **[63.1]**

$$\frac{da}{dN} = C \Delta K^m \qquad (1)$$

is used. Here C and m are empirical constants, which have to be determined by crack growth tests.
The new formula is based upon well-known parameters such as the modulus of elasticity E, the yield strength f_y, the true fracture stress f_t, the critical stress intensity factor K_{IC} and of course the geometrical dimensions of the actual cracked specimen.
A large number of fatigue tests have been performed earlier, and some of these have been compared with the new formula in an earlier paper **[91.1]**. The comparison did show very good agreement. However unfortunately most of the tests were not supported with all the relevant parameters, especially the true fracture stress f_t and the K_{IC} - K_I relation. These parameters therefore had to be estimated as far as possible.
In this project a new series of fatique tests is performed, where all the relevant parameters are measured. The chosen materials are two high strength aluminiums Al2024 and Al7075 and one high strength steel Hardox400.
To determine all the parameters it is necessary to establish three kinds of tests. At first a simple tension test with the purpose to determine the modulus of elasticity, the yield strength and finally the true fracture stress. Secondly it is important to determine the critical stress intensity factor for instance by using the ASTM standard test [70.1] and finally to perform a fatigue test, where the relationship between the crack lengt a and the number of cycles N is measured.

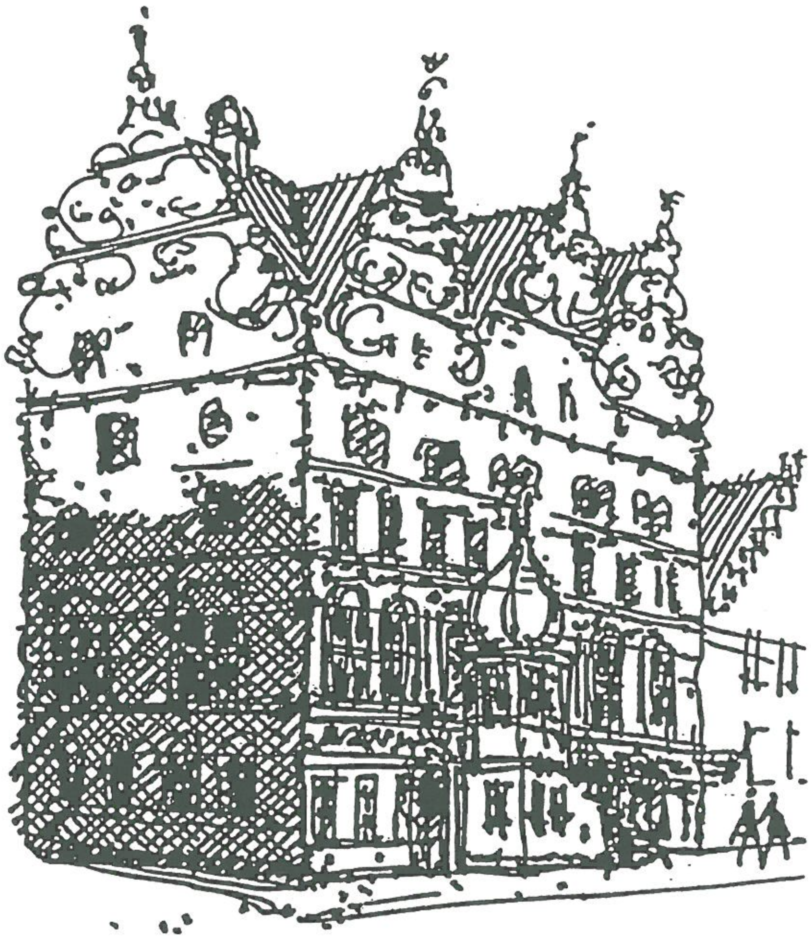
APPENDIX D

Workshop, November 13 - 14, 1996

DYNAMICS OF STRUCTURES

2nd workshop on dynamic loads and
response of structures and soil dynamics

AALBORG UNIVERSITY
DENMARK
November 13 - 14, 1996



PROGRAMME

Wednesday, November 13

17.00	Welcome. Hall, Building A, Sohngårdsholmsvej 57, 9000 Aalborg
17.15 - 19.00	Visit in the laboratories
20.00	Dinner at downtown restaurant "Kniv og Gaffel", Maren Turisgade 10, 9000 Aalborg

Thursday, November 14

Lecture hall F108, Sohngårdsholmsvej 57, 9000 Aalborg

09.00	Welcome / Lars Pilegaard Hansen	
Session 1	**Modelling of Dynamic Loads** Chairman: Søren R.K. Nielsen	
09.05 - 09.25	Steen Krenk:	Modelling of Wind Loads
09.25 - 09.45	Jeppe Jönsson:	Computational Investigation of Repetitive Vertical Human Loading
09.45 - 10.05	Kim Mørk:	Design Criteria for Submarine Pipelines Subjected to Vortex Induced Vibrations
10.05 - 10.25	B. L. Josefson et al:	Mechanical Energy Flow in Vibrating Structures
10.25 - 10.45	Allan Larsen:	Elements in Aerodynamic Flutter Control
10.45 - 11.15	Coffee	
Session 2	**Dynamic Properties of Materials** Chairman: Jørgen S. Steenfelt	
11.15 - 11.35	Lars Bo Ibsen:	Bearing Capacity of Foundations Subjected to Impact Loads
11.35 - 11.55	Mikael Enelund:	Formulation and Integration of Standard Linear Solid with Integer and Fractional Rule Laws
11.55 - 12.15	Thomas C. Hansen:	Fatigue and Crack Propagation in Structural Materials
12.15 - 12.35	B. Skallerud and Z.L.Zhang:	Numerical Analysis of Damage Evolution in Cyclic Elastic-Plastic Crack Growth Problems
12.35 - 12.55	Poul Lade:	Rotational Kinematic Hardening Model for Sand
13.00 - 14.00	Lunch	
Session 3	**Dynamic Analysis of Structures** Chairman: Lars Pilegaard Hansen	
14.00 - 14.20	Søren R. K. Nielsen/ Henriette Hansen:	Active Vibration Control
14.20 - 14.40	Helge Gravesen and Morten Faurskov:	Displacements of Øresund Bridge Piers from Ship Impact
14.40 - 15.00	Poul S. Skjærbæk:	Earthquake Tests of Reinforced Concrete Frames

Dynamics of Structures
2 nd Workshop - Aalborg - November 13 - 14, 1996

Participants

Andersen, Knut H.	NGI, Norway
Andersen, Palle	AAU, Denmark
Andrén, Peter	KTH, Sweden
Asmussen, John	AAU, Denmark
Brincker, Rune	AAU, Denmark
Bødker, Lars	AAU, Denmark
Enelund, Mikael	CTH, Sweden
Faurschou, Morten	Carl Bro a/s, Denmark
Gravesen, Helge	Carl Bro a/s, Denmark
Hansen, Henriette	AAU, Denmark
Hansen, Svend Ole	Svend Ole Hansen, Denmark
Hansen, Lars Pilegaard	AAU, Denmark
Hansen, Thomas Cornelius	H+H Industri, Denmark
Ibsen, Lars Bo	AAU, Denmark
Jacobsson, Lars	CTH, Sweden
Jakobsen, Kim Parsberg	AAU, Denmark
Jensen, Jakob Laigaard	COWI, Denmark
Josefson, Lennart	CTH, Sweden
Jönsson, Jeppe	ES-Consult A/S, Denmark
Kirkegaard, Poul Henning	AAU, Denmark
Krenk, Steen	Lund University, Sweden
Lade, Poul	The John Hopkins University, USA / AAU, Denmark
Larsen, Allan	COWI, Denmark
Mørk, Kim	Det Norske Veritas, Norway
Nielsen, Søren R.K.	AAU, Denmark
Oscarsson, Johan	CTH, Sweden
Petersson, Martin	CTH, Sweden
Rasmussen, Klaus	AAU, Denmark
Rytter, Anders	Rambøll, Denmark
Skallerud, Bjørn	The Norwegian Inst. of Techn, Norway /AAU,Denmark
Skjærbæk, Poul S.	AAU, Denmark
Steenfelt, Jørgen S.	AAU, Denmark
Sørensen, John Dalsgård	AAU, Denmark
Thesbjerg, Leo	Rambøll, Denmark
Thorbek, Lars	Svend Ole Hansen, Denmark
Wilson, Anders	CTH, Sweden

Secretariat: Pernille Sørensen, AAU, Denmark

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APPENDIX E

Information day, November 26, 1997

KONSTRUKTIONERS DYNAMISKE FORHOLD **AALBORG UNIVERSITET**
Lars Pilegaard Hansen **Sohngårdsholmsvej 57, 9000 Aalborg**
Direkte telefon: 96 35 85 85 **Fax: 98 14 23 66** **email: i6lph@civil.auc.dk**

ORIENTERINGSDAG OM DYNAMIK RAMMEPROGRAMMET

ONSDAG D. 26. NOVEMBER 1997

Medarbejdere ved I5 og I6 samt andre interesserede inviteres hermed til en orienteringsdag om rammeprogrammet "Dynamics of Structures", som finansieres af Statens Teknisk- Videnskabelige Forskningsråd (STVF). Programmet startede i 1993 og slutter med udgangen af 1997.

Formålet med programmet er at udføre forskning og forskerudddannelse inden for emnerne dynamisk last samt respons af konstruktioner herunder fundamenter. Karakterisering og modellering af materialer under tidsvarierende laster er også en del af programmet. Der er benyttet analytiske, numeriske samt eksperimentelle metoder.

Der er afholdt workshops i forbindelse med rammeprogrammet efteråret 1994 og efteråret 1996, hvor medarbejdere finansieret af rammeprogrammet samt andre foredragsholdere har fortalt om emner inden for rammeprogrammets område.

Formålet med denne orienteringsdag er at præsentere nogle af resultaterne for instituttemes medarbejdere. Det vil hovedsageligt være projekter, som lige er afsluttet eller som er nær sin afslutning.

Hver præsentation har en varighed på 30 min., hvoraf de 20-25 min. er til selve præsentationen og de resterende 5-10 min. er til diskussion.

Præsentationerne vil blive givet på engelsk eller dansk efter foredragsholderens ønske.

I forbindelse med slutrapporteringen til STVF vil der blive udgivet en publikation over rammeprogrammets resultater. Denne vil foreligge omkring 1. april 1998. Interesserede kan til den tid få et eksemplar ved henvendelse til Pernille Sørensen, I5, lokal 8484.

På side 2 er programmet for orienteringsdagen anført og på side 3 en tilmeldingskupon, som bedes afleveret til Pernille Sørensen, I5, snarest og senest d. 14. november 1997.

Med venlig hilsen

Lars Pilegaard Hansen

Orienteringsdag om Dynamikrammeprogrammet den 26. november 1997

Tak for din tilmelding til ovennævnte arrangement.

Orienteringsdagen afholdes som planlagt, dog med den ændring at frokosten vil være **vederlagsfri** for alle deltagerne i modsætning til tidligere meddelt. Såfremt der skulle være deltagere der ikke ønsker at deltage i frokosten, bedes dette meddelt til Pernille, senest den 24.11.97.

Programmet er som følger:

Sted: Auditorium F108, Sohngaardsholmsvej 57, 9000 Aalborg

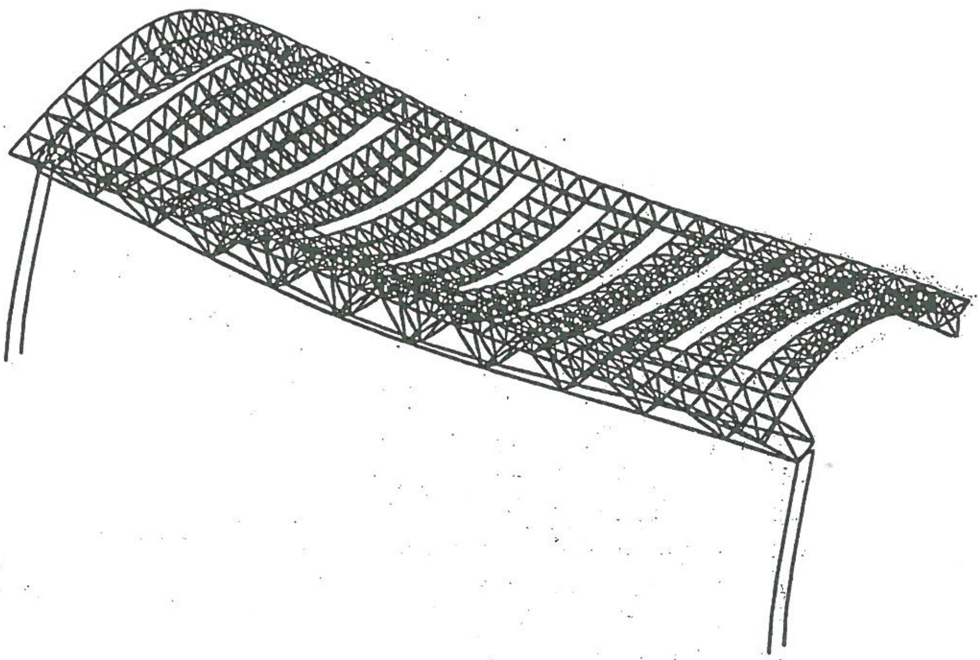
10.30 - 10.45:	Velkomst samt kort orientering om rammeprogrammet Lars Pilegaard Hansen
10.45 - 11.15:	Identification of civil engineering structures using vector ARMA models Palle Andersen
11.15 - 11.45:	Modal analysis based on the RD techniques John Asmussen
11.45 - 12.15:	Heavy vehicles on minor highway bridges. Calculation of dynamic impact factors from selected crossing scenarios Poul Henning Kirkegaard
12.15 - 13.15:	Frokost (vederlagsfri)
13.15 - 13.45:	Wave loading and overtopping on caisson breakwaters in multidirectional braking waves John Grønbech
13.45 - 14.15:	Techniques to determination of E and G on friction and cohesion soil at small strains Jørgen S. Steenfelt
14.14 - 14.45:	Repetitive vertical human load Jeppe Jönsson
14.45 - 15.15:	Kaffe/the (vederlagsfri)
15.15 - 15.45:	Shaking table tests of scale 1:5 reinforced concrete frames Poul Henning Kirkegaard
15.45 - 16.00:	Afslutning

APPENDIX F

Information pamphlet, June 1994

DYNAMICS OF STRUCTURES

A research programme sponsored by
The Danish Technical Research Council



AALBORG UNIVERSITY
and the
TECHNICAL UNIVERSITY OF DENMARK

June 1994

Dynamics of Structures

Dynamics of Structures is a research programme sponsored by the Danish Technical Research Council. The programme started in 1993 and continues to the end of 1997. It is a cooperative effort of the Department of Building Technology and Structural Engineering and the Department of Civil Engineering at Aalborg University, and the Department of Structural Engineering at the Technical University of Denmark.

The purpose of the programme is to conduct research, provide research education and results relating to dynamic loads and response of structures and foundations. The description and modelling of the behaviour of materials under varying loads is also part of the research programme. The research will use and develop both analytical and experimental methods.

Research Areas

Analysis of Structures

The theoretical part of the programme is concerned with mathematical models and computational techniques for describing the development of the response history of structures exposed to varying loads. The specific projects encompass computational techniques for eigenvalue problems and system reduction, nonlinear response analysis, wind load models and vortex-induced vibrations, modelling and simulation of stochastic response of structures.

Efficient techniques for extracting the dynamic characteristics from partial solution of large scale linear and quadratic eigenvalue problems are being investigated. Currently a unified formulation of Lanczos type algorithms with different orthogonalization schemes is being developed.

A new type of solution algorithm for nonlinear structural response is being developed. It is based on the principle of orthogonal residuals, in which the load increment is adjusted to provide a "best" fit to the current displacement. Several different formulations including quasi-Newton stiffness corrections are being investigated.

Wind load is one of the key subjects in the new Eurocode for Actions on Structures, and several aspects of this problem are included in the research programme. Cooperation has been established with related projects on statistical models for turbulence in the natural wind and work on a statistical description of the basic design wind speed including directional effects. In addition, work on computational models for vortex-induced oscillations due to wind is being initiated.
Contacts: S. Krenk (1), S.R.K. Nielsen (1)

Soil Mechanics and Wave Loads

The objective of the soil mechanics part of the programme is to incorporate the dynamic soil parameters in rational numerical models for the description of the structure-foundation interaction, when structures are subjected to dynamic loads. The main effort of the investigation is devoted to structures subjected to critical dynamic loads generated by wind, waves, heavy traffic or machines.

A topic of the programme is the complicated interaction between wave loads and structural response of heavy monolithic caissons and concrete superstructures, with the overall objective to develop a rational method for the design of concrete superstructures on rubble mound breakwaters and the design of monolithic caisson structures on rubble foundation. The interaction between the dynamic wave load and the structural response is poorly known, mainly due to lack of knowledge of the dynamic strength and deformation characteristics of coarse soil material. Consequently, only some very primitive design methods are used today. The special contribution from the project is to provide the soil mechanics part of the design tools. The project is related to the European Marine Science and Technology II Programme and coordinated with the work of an international group on Vertical Wall Breakwaters formed by PIANC.

Another topic in the soil mechanics part of the programme is to study the interaction between vibrating structures and soil. In addition to severe ground motions caused by earthquakes and explosions also ground motions from heavy traffic, fast trains, and machines may damage buildings. The degree of damage depends on the soil layers involved in the problem. Some soil layer, can amplify the motion at specific frequencies, while other soil layers are sensitive to vibration creep or pore pressure build up, which may liquefy part of the subsoil and cause permanent settlement of the soil surface. These phenomena are now studied in detail using advanced equipment and numerical calculations available at the Experimental Center for Dynamics at Aalborg University. The project concentrates on dynamic properties of Danish soil, which is still unknown for most of the soil types. The planned research includes measurements of appropriate soil properties by resonance Coulomb tests and dynamic triaxial tests.
Contacts: L.B. Ibsen (2), H.F. Burcharth (2)

System Identification and Damage Detection

In a damage detection problem, the objective is to identify size, location and consequences of a possible damage by indirect means. This is done by estimating structural changes by experimental modal analysis and then using a model to identify the kind of damage. These techniques are at their early stage of development, and many problems are still unsolved. Three major problems exist: to measure and identify structural properties by unbiased and effective techniques, to combine a large number of independent damage indicators to a meaningful unified damage measure, and to solve the very difficult inverse problem of identifying the size and location for a given set of changes.

In this programme, the main effort is made in the field of development of unbiased effective techniques for estimation of structural parameteres from experimental data. There are projects on application of ARMA models and on development of a new modal analysis technique based on so-called Random Decrement signatures. The advantage of the ARMA-models is that it is the closest one can get to unbiased effective estimators. Further, the variance on all modal parameters can be estimated for each time series. The problem is that the computations are complicated and time-consuming, 10 to 100 times slower than traditional FFT-based techniques. The advantage of the Random Decrement technique is that the technique is leakage free, and that it is very fast, 10 to 100 times faster than FFT-based techniques.

It is the intention to combine the modal analysis techniques with techniques from reliability theory to estimate the probability of structural changes from a set of damage indicators. Recently promising results have been achieved training neural networks to find the size and location of damage from a given set of damage indicators. It is the intention to work with data from both laboratory models and real structures. Laboratory models include different sizes and

types ranging from small well-defined steel models over damaged concrete beams to a 20 m high pylon structure.
Contacts: R. Brincker (1)

Fatigue and Crack Propagation

Many high strength materials have a low crack resistance (fracture thougness K_I), leading to an increased demand on knowledge about crack propagation (fracture mechanics). The scope of this project is to examine crack propagation behaviour of steel and concrete under dynamic load, using a newly developed crack propagation theory. Traditionally crack growth is treated by empirical formulas with experimentally calibrated parameters. The power of the new theory is that it is based on well-known material parameters.

The project involves determination of the critical stress intensity factor K_{IC} using ASTM standard testing procedures, in order to determine how K_{IC} depends on the stress intensity factor K_I. Fatigue tests of CCT specimens and welded connections are carried out to examine the behaviour of crack propagation under dynamic load. Crack propagation in brittle materials like concrete is examined under static load. A new digital processing system to measure crack length is being further developed during the project. The objectives are to develop the theory, so it can be used to predict crack propagation in any structure in order to prevent failure caused by crack growth.
Contacts: M.P. Nielsen (3), L. Pilegaard Hansen (1)

Man-Induced Vibrations

A model for man-induced vibrations, e.g. spectators on grandstands, is being developed. Theoretical considerations based on an impulse balance for the individual person and correlation between a group of persons are being made, and a test programme with laboratory and in-situ measurements is being planned.
Contacts: L. Pilegaard Hansen (1), J. Jönsson (1)

Contact and Information

The results of the research programme are available upon request. Further information about the research programme and its individual projects can be obtained from the indicated contact persons or secretary Pernille Sørensen (1):

1) Department of Building Technology and Structural Engineering,
Aalborg University, Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark
Phone +45 98 15 85 22, Fax +45 98 14 82 43

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APPENDIX G

Progress Report, 1.1.1993 - 31.12.1993 (In Danish)

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23.3.1994

J.nr. 5.26.16.13-1

STVF Rammeprogram: KONSTRUKTIONERS DYNAMISKE FORHOLD

Fremskridtsrapport 1.1.1993 - 31.12.1993 og planer for 1994.

Rammeprogrammet er opdelt i 9 delprojekter, planlagt til etapevis igangsættelse i løbet af 1993-94. Status for de enkelte projekter gives nedenfor med angivelse af ændringer i forhold til planen i ansøgningen.

Som led i rammeprogrammet har professor Niels Saaby Ottosen fra Lunds Tekniske Højskole besøgt AUC og givet en gæsteforelæsning med titlen "A unified approach to high-cycle fatigue" i forbindelse med et projektmøde på AUC den 25. november 1993.

Der er sonderinger igang med henblik på at invitere en internationalt anerkendt forsker inden for området stokastisk dynamik til AUC i 1-2 måneder i 1994.

A. GRUNDLÆGGENDE TEORI

A.1 Modalformer og brug af reduceret basis

Projektet omfatter beregningsteknikker for dynamiske beregninger af større systemer med henblik på at reducere antallet af ubekendte. Steffen Vissing er påbegyndt et Ph.D.-studium ved Institut for Bygningsteknik 1.1.1993, og har siden arbejdet med disse metoder. Det hidtidige arbejde har været dels et litteraturstudium af eksisterende metoder for standard, generaliserede og kvadratiske egenværdiproblemer og dels en opbygning af generelle algoritmer for symmetriske egenværdiproblemer.

Det generaliserede egenværdiproblem består af to globale matricer der ikke nødvendigvis er skaleret ens, ligesom der vil kunne indgå nuldiagonaleelementer stammende fra f.eks. masseløse frihedsgrader eller stivlegemebevægelser. Det er derfor fordelagtigt at arbejde på det generaliserede egenværdiproblem direkte. I denne forbindelse er der udviklet en kompakt udgave af en generaliseret Jacobi algoritme, hvor de to globale matricer diagonaliseres simultant. Ved hver transformation fastlægges derfor to transformationsparametre, hvilket generelt medfører ikke-orthogonale transformationer. Idet udførelse af selve transformationen er relativ dyr i forhold til f.eks beregning af transformationsparametrene udelades transformationer der leder til ingen eller kun meget få ændringer af det globale system. Disse trivielle transformationer identificeres ved transformationsparametrene. Konvergens er afhængig af de globale matricers diagonaldominans. Algoritmen er implementeret i C, *Vissing & Krenk (1993)*.

For systemer med et stort antal af frihedsgrader vil der ved Jacobi algoritmen skulle en del forholdsvis dyre transformationer til for at løse problemet. For at beskrive en konstruktions dynamiske respons approximativt vil det være tilstrækkeligt at fastlægge et reduceret antal af modalformer svarende til de mindste egenfrekvenser. Subspace algoritmen er et eksempel på at udtage et reduceret antal modalformer. Her udvælges et underrum ved et antal startiterationsvektorer hvorpå der opstår et egenværdiproblem af samme dimension som underrummet. Første approximation til egenværdier og modalformer fastlægges ved løsning af egenværdiproblemet med den generaliserede Jacobi algoritme. Approximation af modalformerne for det oprindelige system fastlægges og indgår som nye iterationsvektorer. Forløbet gentages indtil et ønsket antal af de mindste egenværdier har konvergeret. Algoritmen er ligeledes implementert i C, *Vissing & Hededal (1993)*.

Metoderne har dog den svaghed at en eventuel profilstruktur af de globale matricer ødelægges. Der findes forskellige explicitte metoder for reducering af profilstrukturen for matricer. Et eksempel er Householders metode, der kan tridiagonalisere en enkelt matrix ved et endeligt antal transformationer. Hver transformation forgår som en spejling af en vektor beskrevet ved en søjle i matricen. En af studiets faser har været et forsøg på at generalisere Householder tridiagonalisering af en enkelt matrix til også simultant at tridiagonalisere to matricer beskrivende det generaliserede egenværdiproblem. Dette har dog vist vanskeligheder ved uønsket udfyldning af profilen.

Nu er der lagt vægt på algoritmer af Lanczos type, hvor der opbygges et vektorrum som udspænder modalformerne svarende til de mindste egenværdier. Dette vektorrum opbygges trinvist som invers vektoriteration og ved at påtvinge orthogonalitet til foregående vektorer. Problemet reduceres til et standard egenværdiproblem med en enkelt tridiagonal matrix. Lanczos algoritmen er numerisk ustabil og kombineres derfor ofte med en form for reorthogonalisering. Der er også muligheder for at behandle det kvadratiske egenværdiproblem. Egenværdiløsning for systemer indeholdende tridiagonale matricer kan udføres effektivt ved f.eks. QR-metoder eller Cholesky algoritmer.

Der arbejdes også med ikke-lineære løsningsteknikker. Der er udviklet en ny algoritme baseret på ortogonalitet mellem residualkraften og det aktuelle flytningsinkrement *Krenk (1993a)*. Metoden har vist sig meget effektiv og robust. Den er udvidet til også at omfatte en kvasinewton korrektion *Krenk & Hededal (1993)*. Arbejdet har været præsenteret på to konferencer *Krenk (1993c,d)* og indgår i et nyt kursus om ikke-lineær analyse med elementmetoden, der bl.a. har været givet for Ph.D.-studerende ved Lunds Tekniske Højskole *Krenk (1993b)*.

Der har i forbindelse med projektet været besøg af 1 uges varighed af to forskere fra Lunds Tekniske Højskole. Tekn. Dr. Håkan Carlsson besøgte AUC i forbindelse med arbejde på Lanczos algoritmer for dæmpede systemer, og Tekn. Dr. Matti Ristinmaa deltog i arbejde vedrørende den ortogonale residualmetode. Begge forbindelser forventes udbygget i 1994.

Publikationer og konferencer:

S. Krenk (1993a), An orthogonal residual procedure for nonlinear finite element equations, Engineering Mechanics Paper No 18, AUC, July (antaget af International Journal of Numerical Metods in Engineering.)

S. Krenk (1993b), *Nonlinear Analysis with Finite Elements*, AUC, September, pp. 140.

S. Vissing & O. Hededal (1993), A subspace algorithm, Engineering Mechanics Paper No 17, AUC, June.

S. Vissing & S. Krenk (1993), A generalized Jacobi algorithm, Engineering Mechanics Paper No 15, AUC, May.

S. Krenk (1993c), Solution of nonlinear finite element equations by an orthogonal residual procedure, *Progress in the Theory and Application of the Finite Element Method II*, Chalmers, Göteborg, August 26-28.

S. Krenk (1993d), A unified approach to nonlinear finite element solution procedures, *Sixth Nordic Seminar on Computational Mechanics*, Linköping, Sweeden, October 18-19.

S. Krenk & O. Hededal (1993), A dual orthogonality procedure for nonlinear finite element equations, Engineering Mechanics, Paper No 21, AUC, November.

A.2 Selvinducerede svingninger

Der er gennemført et eksperimentelt program vedrørende vindinducerede svingninger hos S.O. Hansen ApS. Arbejdet er blevet udført som afgangsprojekt ved DTH af to studerende under rammeprogrammet "Sikkerhed og Pålidelighed". Resultaterne vil blive gjort til genstand for nærmere analyse i 1994 og opstilling af en mekanisk model vil blive forsøgt.

Der er arbejdet med simulering af turbulent naturlig vind i samarbejde med Jakob Mann på Risø. Teknikken bygger på at kombinere den hurtige Fourier transformation med en af Jakob Mann udviklet anisotrop tensor-repræsentation af turbulensen. Metoden blev præsenteret på ICOSSAR '93 i Innsbruck *Mann & Krenk (1993).*

Publikationer og konferencer:

J. Mann & S. Krenk (1993), Fourier simulation of a non-isotropic wind field model, *6'th International Conference on Structural Safety and Reliability*, Innsbruck, 9-13 August.

A.3 Dynamisk respons af konstruktioner med stokastiske materialeegenskaber

Der var under dette projekt afsat midler til 1 måneds ophold for S.R.K. Nielsen ved Princeton i 1993 og 1994. Projektet forløber planmæssigt. Opholdet ved Princeton, der var planlagt til 1994, er dog flyttet til februar 1994.

B. EKSPERIMENTELLE TEKNIKKER

B.1 Skadesdetektering i konstruktioner med stokastisk belastning.

Palle Andersen er påbegyndt et Ph.D.-studium ved Institut for Bygningsteknik 1.9.1993. Formålet med projektet er at udvikle robuste skadesdetekteringsteknikker, der kan detektere og lokalisere skader i konstruktioner. Disse teknikker vil blive baseret på kalibering af ARMA modeller i tidsdomænet. Alt vil blive udført med henblik på implementering i PC-baseret programmel.

I den første måned blev der foretaget et indledende litteraturstudie for at give indblik i ARMA modeller og deres anvendelse indenfor systemidentifikation af bærende konstruktioner.

I perioden 1.9. til 1.10. er programmeret en Gauss-Newton optimeringsalgorime, der kan tilpasse en vilkårlig ARMA model til et målt signal og derefter beregne systemets modalparametre. Til verifikation af optimeringsresultatet programmerede jeg en postprocessor, der grafisk kunne vise de statistiske resultater, der var knyttet til modellen. Postprocessoren omfattede kontrol af hvidstøjsantagelse og sammenligning af responsspektre, henholdsvis beregnet vha. modellen og vha. FFT. Yderligere kunne modellens poler og nulpunkter plottes i det komplekse plan sammen med deres tilhørende standardafvigelser.

Udviklingstiden for dette program var forholdsvis kort, da det blev udviklet i sproget Pascal, Programmet skal tjene som prototype for et C++ program.

Omkring 1.11.1993 startede arbejde med C++. Dette tog udgangspunkt i det udviklede Pascal program. Der er sat visse krav til programmet, specielt mht. mængde af data og hastighed. For at opfylde disse programmeres objektorienteret. Denne programmeringsform gør det let at udskifte dele af optimeringsrutinen uden en alt for stor arbejdsindsats.

Eftersom opstartsbetingelserne i et optimeringsproblem bør være så gode som overhovedet muligt, afsættes tid til at analysere forskellige opstartsbetingelsers indflydelse på konvergenshastighed og det endelige resultat.

Det er hensigten, at de udviklede programmer skal indgå i et software-baseret instrument, som indtil videre betegnes en ARMA-analyzer. Sideløbende med udarbejdelsen af ARMA-analyzeren er det meningen, at indlede skadesundersøgelser på betonbjælker.

B.2 Modalanalyse på Random Decrement Signaturer

Projektet forventes igangsat medio 1994 som planlagt.

B.3 Udmattelse og revneudbredelse

Thomas Cornelius Hansen er pr. 1.1.1993 ansat ved Afdelingen for Bærende Konstruktioner, DTH som Ph.D.-studerende. Der er i projektet følgende ændringer i forhold til den oprindelige plan.

Forsøgsserien til undersøgelse af den kritiske spændings intensitets faktor K_{IC}'s afhængighed af udmattelses intensiteten K_I er under forberedelse og planlægges udført på AUC i løbet af andet halvår 1994. Det har ved tidligere undersøgelser vist sig at revnevækst under udmattelse (dynamisk belastning) afhænger af denne ændring i K_{IC}, hvilket vil blive verificeret ud fra sammenholdelse af forsøgsresultaterne og teoretiske beregninger ved brug af revnevækst teorien. Delprojektet er forsinket grundet vanskelig og tidskrævende resultatbehandling af det oprindelige projekt, der danner basis for projektet. I stedet er undersøgelsene på beton opstartet i 1993 (se nedenfor). Disse undersøgelser refererer til pkt. 5 i den oprindelige projektplan, og var i henhold til denne planlagt opstartet i 1994.

Pkt. 3 i oprindelig projektplan, der indebærer videreudvikling af et digitaliseringssystem, er tilknyttet pkt. 1, hvorfor det af naturlige årsager ligeledes er flyttet til 1994.

Delprojekt 2, der omfatter undersøgelse af revnevækst i svejste konstruktioner, er ligeledes skubbet frem til 1994, da det omfatter samme teoretiske baggrund, som de dynamiske udmattelsesforsøg på almindelige kærvede emner (projekt 1). I dette projekt vil forsøgsresultater blive sammenholdt med bregninger med revnevækst formlen.

En forsøgsserie med kærvede kubiske emner af beton er gennemført på ABK-DtH, hvor det med succes lykkedes at følge Snap-back på last-udbøjningskurven. Resultaterne er i øjeblikket ved at blive teoretisk analyseret.

Forsøgsserien, der skal benyttes til at undersøge betons brudmekaniske egenskaber under tryk, med henblik på at samle resultater, der vil blive analyseret med revnevækstteorien er udsat til sidste halvdel af 1994, grundet nødvendige forstudier af beton under tryk. Disse forstudier er igangværende på ABK-DtH og indebærer triaxiale trykforsøg på beton.

C. UDVALGTE KONSTRUKTIVE PROBLEMER

C.1 Geoteknisk bæreevne for dynamisk belastede konstruktioner.

Dette projekt er en revision af det oprindelige projekt C.1, der forventes igangsat medio 1994 som planlagt.

Den geotekniske bæreevne for konstruktioner vurderes ofte på grundlag af en kinematisk brudfigur. I projektet søges denne beregningsmåde udvidet til dynamiske belastningssituationer ved dels at medtage inertikræfter, dels at benytte passende justerede materialeparametre. Projektet vil omfatte forsøg for dynamiske materialeparametre, modelforsøg og beregninger af disse.

C.2 Bølgelast på kornede medier

På grund af professor Moust Jacobsen's død i 1992 ledes den geotekniske del af projektet fremover af adjunkt Lars Bo Ibsen. Projektet indgår i et større forskningssamarbejde om friktionsmaterialers (fin sand, sand, grus og sten) dynamiske egenskaber. Forskningssamarbejdet er etableret mellem Delft Geotechnics, Norges Geoteknisk Institut og AUC for at afklare de mekanismer, der forekommer, når friktionsmateriale påføres varierende belastninger. En afklaring af disse mekanismer er nødvendig for at kunne opstille realistiske dimensioneringsprocedurer. Ved at projektet indgår i ovennævnte samarbejde anses det videnskabelige niveau og derved projektets resultat, for at være styrket.

Foruden Lars Bo Ibsen har projektet haft dipl. ing. Juraj Blanar tilknyttet i perioden 01.11.1993 - 31.02.1994. Juraj Blanar kommer fra Slovakiet og har modtaget et 4 måneders forskningsstipendium af den danske stat og påfører derfor ikke projektet udgifter. Hans opgave har været at udføre en del af de i projektet planlagte forsøg. Parallelt hermed er civilingeniør Lars Bødker ansat på projektet.

I projektet skal friktionsmaterialets styrke- og deformationsparametre bestemmes eksperimentelt ved såvel statiske som dynamiske triaxial- og pladebelastningsforsøg. Funderingslaboratoriet, der er tilknyttet det dynamiske målecenter, råder idag over et avanceret pladebelastningsapparatur til udførelse af de i projektet planlagte pladebelastningsforsøg på grus og sten. På grund af ønsket om at udføre forsøgsserier på grus og sten har det imidlertid været nødvendigt at designe og fremstille et stort triaxialapparat for at kunne gennemføre denne del af projektet. For at kunne finansiere fremstillingen af dette store triaxialapparat er lønmidlerne på 72.000 kr. i 1993 overført til apparatur. Forpligtelserne over for rammeprogrammet bliver imidlertid tilgodeset ved at knytte Juraj Blanar til projektet. Endvidere har funderingslaboratoriet finansieret tilknytning af pladesmed Jens Ildal svarende til fire måneders arbejde til projektet. Jens Ildals opgave har været at fremstille ovennævnte apparatur.

Arbejdet i perioden 01.08.93-31.12.93 har dels bestået i at dimensionere og fremstille det store triaxialapparat og dels i at udføre klassifikations og triaxialforsøg. Fremstillingen af det store triaxialapparatur er tilendebragt og apparaturet er taget i brug. I perioden er der ligeledes udført et stort antal klassifikationsforsøg. Klassifikationsforsøgene er udført for at udvælge det materiale forsøgene i projektet udføres på. Kravet til udvælgelsen af materialerne har været at de skulle udvælges således at materialerne dækker kornstørrelser fra fint sand til groft grus. Endvidere skal korn partiklerne have samme form, angularitet, samt hvis muligt være opbygget af de samme mineraler. Resultater af disse forsøg har ført til at materialerne i Tabel 1 er valgt. Der er ingen ændringer til det oprindelige projektoplæg, og projektet følger den opstillede tidsplan.

	Baskarp no 15	Blokhus sand	Lund no 0	Portland 8-16 mm	Portland 16-32 mm
d_{50} mm	0.14	0.17	0.35	12	20.5
$U = \frac{d_{60}}{d_{10}}$	1.78	1.5	2.2	1.56	1.42
d_s	2.644	2.646	2.647	2.642	
e_{max}	0.858	0.834	0.889	1.009	
e_{max}	0.549	0.565	0.524	0.698	

Tabel 1. Resultaterne af klassifikationsforsøgene for de valgte materialer.

For at fastlægge og forstå jords dynamiske egenskaber er det nødvnedigt først at fastlægge de statiske styrke/deformationsparametre. For Baskarp no 15, Blokhus sand og Lund no 0 er der i perioden udført statiske triaxial forsøg. For hver sand type er der udført 3 forsøgsserier med varierende poretal. Resultaterne af disse forsøg er indført i en database til kommende behandling.

Publikationer og konferencer:

H.F. Burcharth & L.B. Ibsen (1993), Modelling of storm history with respect to the pore pressure generation. *Monolitihic (vertical) Coastal Structures, First Project Workshop*. Madrid 13-14, October.

C.3 Sportsstadioners dynamik

Projektets planlagte start medio 1993 har måttet udsættes p.gr. af et ekstraordinært arbejde med Eurocode 1 vedrørende vindlast. Forventes startet primo 1994 med deltagelse af Lars Pilegaard Hansen og Jeppe Jönsson.

BUDGET OG REGNSKAB

Regnskabsstatus for finansåret 1993 fremgår af nedenstående skema. Tabellen er opstillet ud fra AUC's regnskabstal. Overførsler til DTH til projekt B3 er optaget særskilt, da de ikke figurerer som udgiftsposter i AUC's regnskab.

Status ultimo 1993 opdelt på projekter

	Status	Budget	+/-	Bemærkninger
Administration	49.398,38	88.000	+ 38.601,62	
A1	301.260,17	437.750	+ 136.489,83	1) EDB 110.000
A2	33.712,14	55.640	+ 21.927,86	
A3	0	20.600	+ 20.600,00	2) Rejse 20.000
B1	20.182,43	159.650	+ 139.467,57	3)
B2	0	0	0	
B3 (AUC)	117.859,33	375.950	+ 258.090,67	
C1	0	0	0	
C2	275.080,08	89.610	- 185.470,08	4)
C3	0	164.800	+ 164.800,00	5) Udsat til 1994
Bogført AUC	797.492,53	1.392.000	+ 594.507,47	
B3 (DTH)	182.680,00	0	- 182.680,00	Løn og uddannelsesomk. for Thomas C. Hansen
B3 (DTH)	80.340,00	0	- 80.340,00	Forsøg
Bogført DTH	263.020,00	0	- 263.020,00	
Bogført ialt	**1.060.512,53**	**1.392.000**	**+ 331.487,47**	

Til regnskabet knyttes følgende bemærkninger:

1) I projekt A1 er anskaffelse af en arbejdsstation til kr. 110.000 udskudt til 1994. Anskaffelse er under forhandling.

2) Forskningsophold ved Princeton er afholdt februar 1994.

3) Udgifter delvis afholdt via AUC.

4) Merforbrug til apparatur afholdt ved omlægning inden for rammeprogrammet, se bl.a. note 3.

5) Projekt igangsat primo 1994.

Regnskabet er opstillet efter udgiftskategorierne i nedenstående skema.

Status ultimo 1993

J.nr. 5.26.16.13-1	Ultimo 1993	Budget 1993	Balance
VIP løn	541.032 kr.	770.000 kr.	228.968 kr.
TAP løn	67.925 kr.	125.000 kr.	57.075 kr.
Apparatur	185.893 kr.	210.000 kr.	24.107 kr.
Drift	253.955 kr.	246.000 kr.	- 7.955 kr.
Adm. Bidrag	11.708 kr.	41.000 kr.	29.292 kr.
Bogført	**1.060.513 kr.**	**1.392.000 kr.**	**331.487 kr.**

Som nævnt i forbindelse med de enkelte projekter og i bemærkningerne til regnskabet er visse poster udskudt til 1994. Der søges om overførsel af det samlede beløb på kr. 331.487, disponeret som vist i nedenstående tabel. Det fremgår af tabellen at der søges om uspecificeret overførsel af kr. 36.687, svarende til ca 2,6% af 1993-bevillingen.

Overførsel til 1994	
A1: EDB, arbejdsstation	110.000,00
A3: forskningsophold afholdt i februar 1994	20.000,00
C3: projekt udsat. Påbegyndt primo 1994	164.800,00
Restbeløb ca. 2,6% af 1993-bevillingen	36.687,47
Ialt	331.487,47

Aalborg, den 23.3.1994.

Steen Krenk
Programleder

APPENDIX H

Progress Report, 1993 - 1994

Regnskabet er opstillet efter udgiftskategorierne i nedenstående skema.

Status ultimo 1993

J.nr. 5.26.16.13-1	Ultimo 1993	Budget 1993	Balance
VIP løn	541.032 kr.	770.000 kr.	228.968 kr.
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Aalborg, den 23.3.1994.

Steen Krenk
Programleder

APPENDIX H

Progress Report, 1993 - 1994

DEPARTMENT OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
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J.nr.5.26.16.13

Dynamics of Structures
Progress Report 1993-1994

INTRODUCTION

Dynamics of Structures is a research programme sponsored by the Danish Technical Research Council. The programme started in 1993 and is planned to continue to the end of 1997. It is a cooperative effort of the Department of Building Technology and Structural Engineering and the Department of Civil Engineering at Aalborg University and the Department of Structural Engineering at the Technical Univerity of Denmark.

The purpose of the programme is to conduct research and to provide research education and results relating to dynamic loads and response of structures and foundations. Characterisation and modelling of materials under varying loads is also part of the research programme. The research will develop and use both analytical, numerical and experimental methods.

The problem areas dealt with in the research programme are: Analysis of Structures, Soil Mechanics and Wave Loads, System Identification and Damage Detection, Fatigue and Crack Propagation, and Man-Inuced Vibrations. This progress report is organized according to the structure of the original proposal with the following projects:

A: BASIC THEORY

- A1. Mode Shape and Reduced Base Techniques.
- A2. Wind Loads on Structures.
- A3. Dynamic Response of Structures with Stochastic Properties and Excitation.

B: EXPERIMENTAL TECHNIQUES

- B1. Damage Detection in Structures under Random Loading.
- B2. Modal Analysis Based on Random Decrement Signatures.
- B3. Fatigue and Crack Propagation.

C: SELECTED DYNAMIC PROBLEMS

- C1. Behaviour of Soil Subjected to Dynamic Loads.
- C2. Dynamic Response of Coarse Granular Materials to Wave Load.
- C3. Dynamics of Sports Stadiums.
- C4. Dynamic Measurements on the Frejlev Mast.

GENERAL STATUS

The project structure of the research programme conforms closely with that of the original proposal. The following changes have occurred: The contents of Project C1 has been adjusted following the untimely death of Professor Moust Jacobsen, Project A3 has been continued and now covers the activities of an AUC-financed Ph.D. student relating to the subject, and Project C4 is a specific activity originated within Projects B1 and B2 and planned to start in 1995.

Summary of Research

Within basic theory substantial progress has been made concerning a generalized eigenvalue algorithm for dynamics and stability problems, a solution technique for nonlinear finite element problems, and modelling and simulation of structures with stochastic properties. Also some work has been made on wind loads. Details are given in sections A1-A3 below.

The experimental techniques have concentrated on damage detection and crack propagation. The work on damage detection covers ARMA modelling and system identification and Random Decrement technique as described in B1 and B2. Damage detection by neural network techniques has also been considered. The crack propagation work of B3 has concentrated on failure of concrete, but will concentrate on fatigue crack propagation in 1995.

The geotechnical projects C1 and C2 have covered foundation design of breakwaters, experimental characterisation of granular materials and dynamic properties of soils, and theoretical material models for granular materials. Work on man-induced vibration from spectators has been initiated in 1994 in project C3, and a new project C4 is planned for dynamic measurements and system identification of a large guyed mast.

All projects in the original plan have been started. The status is satisfacory on all projects and many external relations have been established. In particular the four projects A1, A3, B1 and C2 have a very high level of activity, clearly demonstrated in the substantial number of publications.

Research Education

The research programme finances five Ph.D. students, and one additional Ph.D. student is financed by Aalborg University and attached to project A3. Aalborg University has contributed to financially to two of the Ph.D students in the research programme as illustrated in the Table, giving dates and relative financing in months.

Table 1: Ph.D. student enrollment in programme

Ph.D.	Project	Period	AUC	STVF
Steffen Vissing	A1	01.01.93-31.12.95	0	36
Poul S. Skjærbæk	A3	01.09.94-31.08.97	36	0
Palle Andersen	B1	01.09.93-14.02.97	6	30
John Asmussen	B2	01.09.94-31.08.97	6	30
Lars Bødker	C1	01.07.94-30.06.97	0	36
Th. Cornelius Hansen	C3	01.01.93-31.12.97	0	36

External Contacts and Information

Most projects have established international working contacts as indicated in sections on the individual projects. The research programme will receive a three months visit via the EU Human Mobility Programme, and also interacts with the EU Marine Science and Technology (MAST) Programme.

An information leaflet 'Dynamics of Structures' was sent out in June 1994 together with an invitation to a workshop on dynamics of structures 14-15 September, 1994. The workshop contained presentation of laboratory facilities at Aalborg University for Dynamics of Structures and 14 presentations - 10 from the research programme and 4 external. The manuscripts of the presentations were made available during the workshop. A total of 25-30 attended the workshop, that was generally considered a success. It is the intention to have a workshop every year of the programme, and an effort will be made to increase the number of external participants.

A: BASIC THEORY

A1. Mode Shape and Reduced Base Techniques

Project content and status

The purpose of the project is to develop computational techniques suitable for models with a large number of degrees of freedom in which a reduced basis is used for the full of a linited part of the problem. The main effort has been devoted to the reduction and efficient solution of the generalized eigenvalue problem. This problem plays a central role in structural dynamics and stability. Also a nonlinear solution technique based on orthogonal increments has been developed.

The vibrations of undamped or damped structures are described by the generalized eigenvalue problem of linear and quadratic type, respectively.

$$(\mathbf{A} + \lambda \mathbf{B})\mathbf{w} \;=\; \mathbf{0} \qquad\qquad (\mathbf{K} + \lambda \mathbf{C} + \lambda^2 \mathbf{M})\mathbf{u} \;=\; \mathbf{0}$$

In structural dynamics the quadratic eigenvalue problem for damped vibrations is often reduced by imposing restrictions on the damping matrix **C** to produce a simple modification of a linear eigenvalue problem. Essentially this amounts to an assumption of uncoupled real modes - i.e. modes with all components in phase. For nontrivial damping the mode shapes as well as the eigenvalues will typically be complex valued.

Preliminary work in 1993 included algorithms for the subspace method for the linear eigenvalue problem. A subspace containing the smallest eigenvalues is found by inverse iteration combined with orthogonalisation to speed up convergence. The algorithms are reported in [A1.1] and [A1.2] including a computer code implementation in C.

The work in 1994 has concentrated on the reduction of quadratic and linear eigenvalue problems to a smaller linear eigenvalue problem of tridiagonal form and the development of an efficient solution method for the reduced problem. The reduction is performed by the Lanczos scheme, in which each iteration increases the dimension of the subspace by one. Work was concentrated on problems with symmetric matrices, and it was realized, that the natural form of the reduced tridiagonal problem, did not use the standard unit matrix, but a diagonal matrix **E** containing a combination of +1 and -1 entries, i.e. a symmetric eigenvalue problem of the form

$$(\mathbf{E} + \lambda \mathbf{T})\mathbf{x} \;=\; \mathbf{0}$$

While this eigenvalue problem is symmetric and tridiagonal, the nondefinite form of the matrix **E** permits complex eigenvalues. A common procedure for the reduction of linear and quadratic eigenvalue problems to this - non-classic - form has been developed and described in [A1.8] and [A1.10].

The new reduced tridiagonal eigenvalue problem with nondefinite diagonal matrix **E** can not be solved by traditional algorithms without destroying its particularly simple and compact form. The traditional method of choice would be the **QR**-algorithm with appropriate shifts. However in the present case this would imply the use of an upper Hessenberg matrix and a unit matrix, instead of the *symmetric* tri-diagonal matrix **T** and **E**. An alternative formulation of the **QR**-algorithm has been developed, that retains the symmetric tri-diagonal form. Like in the original **QR**-algorithm the use of appropriate shifts during iteration is crucial for the efficiency of the algorithm. The reason appears to be that the eigenvalues are liberated in order of increasing magnitude, and if the right shifts were not used, most of the iterations would be used to reshuffle the tridiagonal matrix, one step at a time. Complex aritmetic can be avoided by combining two conjugate complex single shifts into a real-valued double shift. The new generalized **QR**-algorithm with real-valued double shifts is described in [A1.11].

The work on non-linear solution techniques has resulted in the development of the 'orthogonal residual' type of algorithm. The idea is to consider the displacement increment as a 'modal form' that can be increased or decreased in magnitude by the out-of-balance force while retaining its shape. The current magnitude is optimal, if the residual is orthogoanl to the 'modal form'. The original algorithm was reported in [A1.3], and an extension with quasi-Newton correction in [A1.6]. Both papers are in the process of publication as journal articles. Presentation of these methods and their relation to alternative nonlinear solution methods have been given at several conferences [A1.4], [A1.5], [A1.7] and [A1.9].

Plans for 1995

The main task within this project will be the further analysis of the generalized Lanczos reduction and QR algorithm for non-definite linear and quadratic eigenvalue problems with respect to convergence, stability, and efficiency. In particular the quadratic generalized eigenvalue problem corresponding to dynamic systems with nonorthogonal damping will be investigated. In this problem the solution efficiency hinges on the ability of the generalized Lanczos procedure to extract the relevant information in a *limited* number of modes, and the convergence and stability of the generalized QR algorithm with double transformations, accounting for complex conjugate eigenvalues.

Dynamic analysis facilities will be included in the finite element program FEMLAB developed by Krenk & Hededal in 1994 and used to study large order problems on PC and workstation computers. A comparative study with traditional nonsymmetric solution procedures will be carried out, and the use of shifts and different forms of reorthogonalization in the generalized Lanczos reduction procedure will be investigated.

Steen Krenk will mainly be at the Division of Mechanics at Lund University, Sweden in 1995. The project will cooperate with the group working on vibrations and fluid structures interaction at the Division of Structural Mechanics in Lund. Also, contact has been established with a new project on nonsymmetric eigenvalue-problems and fluid-structure interaction at the Technical University of Delft, and Hilda van der Veen will visit during 1995. Steffen Vissing will spend several shorter periods in Lund and Delft during 1995.

Participants

Steffen Vissing, Ph.D. student, Departement of Building Technology and Structural Engineering, Aalborg University. Financed by the research programme from 1.1.1993.

Steen Krenk, Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

A1.1 S. Vissing & S. Krenk, A generalized Jacobi algorithm, Engineering Mechanics Paper No. 15, Aalborg University, June 1993.

A1.2 S. Vissing & O. Hededal, A subspace algorithm, Engineering Mechanics Paper No. 17, Aalborg University, June 1993.

A1.3 S. Krenk, An orthogonal residual procedure for nonlinear finite element equations, *International Journal for Numerical Methods in Engineering* (in press). Engineering Mechanics Paper No. 18, Aalborg University, July 1993.

A1.4 S. Krenk, Solution of nonlinear finite element equations by an orthogonal residual procedure, *Progress in the Theory and Application of the Finite Element Method II*, Chalmers University, Göteborg, August 26-28, 1993.

A1.5 S. Krenk, A unified approach to nonlinear finite element solution procedures, *Sixth Nordic Seminar on Computational Mechanics*, Linköping, October 18-19, pp. 3-18, 1993.

A1.6 S. Krenk & O. Hededal, A dual orthogonality procedure for nonlinear finite element equations, *Computer Methods in Applied Mechanics and Engineering* (in press). Engineering Mechanics Paper No. 21, Aalborg University, November 1993.

A1.7 S. Krenk & O. Hededal, Orthogonal residual solution procedures, *WCCM III, Third World Congress on Computational Mechanics*, Extended Abstracts Vol. II, pp. 1304-1305, Chiba, Japan, August 1-5, 1994.

A1.8 S. Vissing & S. Krenk, Linear and quadratic Lanczos algortihms, *Seventh Nordic Seminar on Computational Mechanics*, Ed. K. Bell, Trondheim, October 4-5, pp. 92-95, 1994.

A1.9 S. Krenk, Orthogonal residual procedures in non-linear mechanics, *DCAMM Anniversary Volume 1994*, Danish Center for Applied Mathematics and Mechanics, Lyngby, October 27-28, pp. 79-98, 1994.

A1.10 S. Vissing & S. Krenk, Linear and quadratic Lanczos algorithms, Engineering Mechanics Paper No. 25, Aalborg University, December 1994.

A1.11 S. Vissing & S. Krenk, Generalized QR algorithm for indefinite symmetric eigenvalue problems, Engineering Mechanics Paper No. 26, Aalborg University, December 1994.

A2. Wind Loads on Structures

Project content and status

The purpose of the project is to establish procedures and collect data for calculation of dynamic wind loads on structures. This includes in particular: wind field representation, extreme wind statistics, dynamic alongwind response, and vortex shedding response. The project is closely related to the dynamic wind response design problems treated in a preliminary form in the new Eurocode 1, Actions on Structures. Improved procedures for calculaing dynamic wind loads and response may have impact on the revision of the Eurocode, planned to take place within 3-4 years.

A wind field simulation procedure has been developed in cooperaion with Jacob Mann at Research Establishment Risø [A2.1]. The influence of the wind gradient on the turbulence is included via a perturbation solution to the Navier-Stokes equations, and good agreement with turbulence measurements is obtained.

The extreme winds in the eastern part of Denmark have been estimated from available data in connection with the Øresund Bridge project. In the present project directional characteristics of the extreme winds for all Denmark will be determined, using the so-called peak-over-threshold method. Three alternative formulations, based on either of the variables wind velocity, wind velocity squared, and wind pressure, are being investigated.

Dynamic along wind response is usually evaluated on the basis of an approximate representation of the structure in the wind field. An improved representation, in which the two dimensions of the structural shape are repreented in a simple explicit format, has been developed and presented to a task gorup for wind load, [A2.2].

Plans for 1995

The investigation of the dynamic extrem wind climate in Denmark will be completed, and the results will be published and included in the Danish design specifications of the Eurocode. A more detailed analysis of the along wind response procedure will be made, including the effect of the length scale of the turbulent wind field. The results will be published and distributed to the members of the Eurocode team on wind load in attempt to improve the present code procedures for dynamic wind load.

There is a general need for design procedures for structures suceptible to vortex shedding. The design procedure must include the essential features, such as shape and frequency, within a suitably simple format. A review of current procedures will be made and one and two degree of freedom systems will be analysed with regard to suitability. Wind tunnel tests will be made in the related project on Safety and Reliablilty of Structures, also sponsored by the Danish Technical Research Council. Part of this work will be carried by M.Sc. Michael Kleiser from Technische Univertität Wien, who will visit Aalborg University for three months in the beginning of 1995 as part of the activities of the Stochastic Mechanics Network under the EU Human Mobility programme.

Participants

Svend Ole Hansen, director and owner of S.O. Hansen ApS, a wind engineering and structural dynamics consulting company.

Steen Krenk, Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Søren R.K. Nielsen, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Michael Kleiser, M.Sc., Technische Universität Wien.

Publications and conferences

A2.1 J. Mann & S. Krenk, Fourier simulation of a non-isotropic wind field model, in *Structural Safety and Reliability, Proceedings of ICOSSAR '93*, Eds. G.I. Schuëller, M. Shinozuka & J.T.P. Yao, Balkema, Rotterdam, Vol. 3, pp. 1669-1674, 1994.

A2.2 S.O. Hansen & S. Krenk, Guidelines for Dynamic Alongwind Response, Technical Note for Task Group on Dynamic Wind Loading, Eurocode 1: Part 2.4 Wind Actions, pp. 9. September 1994.

A3. Dynamic Response of Structures with Stochastic Properties and Excitation

Project content and status

The purpose of the project is to formulate analytical models for the dynamic response of structures with random parameters subjected to stochastic dynamic excitation. The importance of uncertainty of structural parameters such as the reduced bending stiffness in cracked RC-beams are investigated. A finite element program for RC-structures is developed with due consideration of the deterioration of strength and stiffness of structural elements because of bond deterioration, cracking, crushing etc. The programme will be verified by comparing the predicted response with measured values from model tests. Also localization of damages in RC-structures based on measured eigenfrequencies is considered. The robustness and effectiveness of the localization algoritm are tested based on simulated results from the finite element program [A3.1].

The work on the formulation of analytical models for the dynamic response of structures with random parameters subjected to stochastic dynamic excitation has been done in cooperation with H. U. Köylüoğlu and A. Ş.Çakmak, Princeton University, USA. Solutions have been obtained based on first and second order perturbations methods - for linear systems in [A3.2], linearized nonlinear systems in [A3.1], and with a hierarchial approach in [A3.4]. Another solution has been based on stochastic differential equations, introducing the random parameters as extra state variables, [A3.5]. In this case secular terms arising in the transient phase of the response can be omitted. Finally, an non-stochastic interval mapping approach has been applied, and an approach for calculating the failure probability of random structures with many safety margins by mapping the crossing problem into a modal subspace, [A3.6].

The damage localization problem and the response problem has only been considered in a preliminary phase. A method for the prediction of global and localized damage and future reliability for RC-structures subject to earthquakes has been developed based on updating the parameters of an equivalent shear model of hysteretic oscillators, [A3.7]. Further, an approach based on modelling the response by means of neural networks has been attempted, [A3.8].

The project has developed satisfactory during 1994, and all goals have been achieved. Most of the research during 1994 has been financed by the Aalborg University (Søren R.K. Nielsen).

Plans for 1995

By March 1995 a Ph.D. student, Poul S. Skjærbæk, will be attached to the project. Poul S. Skjærbæk will be financed by Aalborg University in support of the effort on dynamics of structures. The project deals with the formulation of numerical models for the response of RC-structures subject to random loadings. Further the possibility is investigated of using global damage indicators estimated from response measurements to detect and localize damage in the structure. It is the plan, that Poul S. Skjærbæk shall concentrate on the development of the finite element program for RC-structure calculations and the damage location problem.

The initial task in the project is to develop a simulation programme for stochastic dynamic analysis of RC-structures which is able to handle panel buildings (structures of slabs and beams). This work will be based on modification of an existing programme SARCOF which has been designed for the analysis of framed structures. Specific slab elements will be developed, taking the stiffness and strength deterioration into account. The stochastic load modelling will still be concentrated on earthquakes.

Based on simulation studies with this programme, the work will next be concentrated on the development of a algoritm for localization of damage in RC-structures subjected to earthquakes. The localization algoritm is based on measured time dependent circular eigenfrequencies $\omega_j(t)$ and damping ratios $\zeta_j(t)$. For a given undamaged jth substructure (ranging from a single beam to half a structure) a linear elastic stiffness matrix $\mathbf{K}_j$ can be assembled. An equivalent linear elastic stiffness matrix for the damaged jth substructure can then be defined as $\mathbf{K}_j D_j(t)$, where $D_j(t)$ is a local scalar damage indicator for the damaged jth substructure ranging from 0 to 1. The damage indicators $D_j(t)$ for the substructures, and hence the localization of the damage, are determined so the equivalent linear system posess the observed undamped circular eigenfrequencies. A similar approach is used for the damping matrix of the substructure, where the local damage indexes for the damping matrices of the substructures are calibrated to display the measured damping ratios.

The uncertainty of the localization is investigated by comparing the predicted localizations by the developed algoritm with simulated damage by SARCOF as a function of the number and location of the sensors.

Søren Nielsen will visit Princeton in 1995.

Participants

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Søren R.K. Nielsen, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

A3.1 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Stochastic dynamics of geometrical non-linear random structures subject to stationary random excitation, *Journal of Sound and Vibration* (in press). Structural Reliability Theory, Paper No. 116, Aalborg University.

A3.2 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Perturbation solutions for random linear structural systems subject to random excitation using stochastic differential equations. Structural Reliability Theory, Paper No. 117, Aalborg University (submitted to *Earthquake Engng. Struct. Dyn.*).

A3.3 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Applications of interval mapping in mechanics for structural uncertainties and pattern loadings. *Journal of Engineering Mechanics* (in press).

Structural Reliability Theory, Paper No. 121, Aalborg University.

A3.4 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Perturbation solutions for non-linear MDOF structures with random properties subject to random excitation using stochastic differential equations. Structural Reliability Theory, Paper No. 133, Aalborg University (submitted to *IUTAM'95*, Trondheim).

A3.5 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Solution of random structural system subject to non-stationary excitation: Transforming the equation with random coefficients to one with deterministic coefficients and random initial conditions. Structural Reliability Theory, Paper No. 134, Aalborg University (submitted to *Earthquake Engineering and Soil Dynamics*).

A3.6 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Reliability approximations for random MDOF structures subject to random dynamic excitation in modal subspaces. Structural Reliability Theory, Paper No. 126, Aalborg University (submitted to *ICASP'95*, Paris).

A3.7 S.R.K. Nielsen, H.U. Köylüoğlu, A.Ş. Çakmak and P. H. Kirkegaard, Prediction of global and localized damage and future reliability for RC-structures subject to earthquakes. Structural Reliability Theory, Paper No. 128, Aalborg University (submitted to *Earthquake Engineering and Structural Dynamics*).

A3.8 S.R.K. Nielsen, H.I. Hansen & P.H. Kirkegaard, Modelling of Deteriorating RC-Structures under Stochastic Dynamic Loading by Neural Networks. *Proc. of the 2nd Int. Conf. on Computational Stochastic Mechanics*, Athens, Greece, June 13-15, 1994. Structural Reliability Theory, Paper No. 125, Aalborg University.

B: EXPERIMENTAL TECHNIQUES

B1. Damage Detection in Structures under Random Loading

Project content and status

The main goal is to develop a robust damage detection technique based on the calibration of the ARMA models for detecting, locating and quantifying damages in structural systems. This includes an investigation of the uncertainties of the modal parameters and mode shapes obtained by time domain ARMA-models for identification of civil engineering structures, and the development of suitable software in a PC environment.

The project started in September 1993 with Ph.D-student Palle Andersen who made a first version of an ARMA calibration programme in C++ based on a Gauss-Newton optimization algorithm. Other optimization algorithms for calibration of ARMA models have been investigated, in particular with regard to estimation and setting of starting values in the ARMA algorithms, which may influence the modal parameters. Also the handling of large data segments and implementation of multi-channel ARMA models have been considered. The resulting preliminary version of a C++ programme for calibration of ARMA models was presented in the September 1994 workshop on "Dynamics of Structures", and a paper presenting a "backward-forecasting" algorithm for ARMAX-models and a comparison with the traditional Gauss-Newton algorithm has been submitted to IMAC13, [B1.1].

In parallel with the development of the C++ programme the ARMA calibration algorithms have also been implemented in MATLAB together with other techniques (ERA,ITD,..) for time domain identification of civil engineering structures. The MATLAB programme is in the form of a STDI-toolbox, (Structural Time Domain Identification) to be used with MATLAB. The development of this toolbox started using a DOS-version of MATLAB, but was later changed to the Windows version in order to use the graphics user interface.

The project also contains a part dealing with damage detection. The software has used in a project on damage detection of concrete beams. In cooperation with the 'Size Effects and Rotation Capacity of Concrete Beams' - sponsored by the Danish Technical Research Council - three concrete beams were made in the summer 1994. These beams were loaded using a traditional servo-hydraulic loading-system in displacement control. At each reloading the beams were excited by a series of pulses using an impact hammer. The measured response was analysed using the C++ ARMA calibration programme. It was found that it was easier to detect a damage in a normally reinforced beam than in a lightly reinforced beam, [B1.2].

Data from one years measurements of the dynamic response of an offshore structure have been obtained from the consulting company INTEVEP A.S in Venezuela and have been analysed with respect to linearity, stationarity, periodicity and normality. Further, the modal parameters have been estimated using an ARMA model [B1.3]. Based on this analysis the possibility of detecting a change in the structure, due to e.g. a damage, has been investigated [B1.4]. Data from the Norwegian Gullfaks offshore platform - obtained from Ivar Langen, Høgskolesenteret i Rogaland - have also been analysed.

Damage assessment consists of locating and quantifying a damage from estimated modal parameters. In order to solve this problem well-known techniques have been considered and a new neural network based has been proposed. This neural network based technique has been tried out on steel beams in the laboratory [B1.5], [B1.6] and on a 20 meter high steel lattice mast [B1.7]. The technique has been compared with well-known techniques [B1.8], [B1.9]. The results from these investigations show that the neural network based technique is superior to other techniques. Especially, due to better results and because it is a technique which can be used on-line.

In 1994 the problem of optimal location of sensors has also been considered. By using a scalar measure of the inverse of the Fisher Information Matrix it is shown in [B1.10] how optimal locations of sensors can be estimated.

In addition to the contact with INTEVEP A.S. cooperation has been established with Anders Rytter from the Applied Mechanics Unit of the European Laboratory for Structural Assessment in Ispra, Italy. In 1994 this cooperation was mainly done in relation to development of the neural network based technique for damage assessment. Further, there has been some research concerning damage assessment of a full-scale 4 storey RC-structure located in the laboratory in Ispra. In this research the neural network based damage assessment technique has been evaluated on a RC-structure. This work has been completed [B1.11]. A FEM model for a steel beam with a crack has been established together with Anders Rytter and Marek Krawczuk from the Polish Academy of Sciences, and the modal parameters calculated using the FEM have been compared with experimentally obtained modal parameters, [B1.12].

A working relation has been established with the subgroup 'monitoring and evaluation' of EG-SEA-AI (European Group for Structural Engineering Applications of Artificial Intelligence). Goals for this group, the name of the participants etc. can be found at the HTTP server *http://www.fen.bris.ac.uk/civil/egseaai-/mande.html.*

The project also cooperates with Dr. Demosthenous, Greece, and Rune Brincker visited Dr. Demosthenous in the summer 1994 in order to present the possibility of using ARMA models for analysis of earthquake data [B1.13].

Plans for 1995

The work on ARMA models include: model reduction and separating closely spaced modes, implementation of a multi-channel ARMA model, and estimation of the uncertainty of modal parameters. In addition there are plans for full-scale measurements on the laboratory steel lattice mast for $\frac{1}{2}$ - 1 year with the aim to establish a robust monitoring system which samples data each time a given trig-condition is exceeded. Various kind of damage will be introduced in the mast during the measurement period. This implies a large amount of data which have to be analysed, thereby complicating the damage assessment. A separate goals is to develop suitable software.

The STDI-toolbox will be completed, and a 'Unified Damage Indicator'. combining changes in several response properties and based on probability of detection will be developed.

Techniques which can be used to solve the inverse damage assessment problem will be considered. Fuzzy logic combined with neural networks seems a to be technique which may be considered.

Palle Andersen will be on maternatiy leave from 9 January to 26 March 1995, and it is intended that he spend 3-4 months in the autumn at a foreign university.

Visits by Prof. Ibrahim, Old Dominion University, and Prof. Piombo, Torino University, are being negotiated.

The cooperation with INTEVEP A.S. 1995 will be discussed at IMAC13 in February 1995. Furthermore a meeting in EG-SEA-AI following the IABSE Colloquium i Bergamo, March 1995, is planned.

Participants

Palle Andersen, Ph.D. student, Department of Building Technology and Structural Engineering, Aalborg University. From 1.9.1993, financed by the research programme from 1.3.1994.

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Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul Henning Kirkegaard, Assistant Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

B1.1 P. Andersen, R. Brincker & P.H. Kirkegaard, On the uncertainty of identification of civil engineering structures using ARMA-models. (to be presented at *IMAC13*, Nashville, 16-19 February 1995).

B1.2 R. Brincker, P. Andersen, P.H. Kirkegaard & J.P. Ulfkjær, Damage detection in laboratory concrete beams. (to be presented at *IMAC13*, Nashville, 16-19 February 1995).

B1.3 P.H. Kirkegaard, J.C. Asmussen, P. Andersen & R. Brincker, An experimental study of an offshore structure. Fracture & Dynamics Paper, No. 59, Aalborg University, 1994.

B1.4 R. Brincker, P.H. Kirkegaard, P. Andersen & M. Matinez, Damage detection of an offshore structure. (to be presented at *IMAC13*, Nashville, 16-19 February 1995).

B1.5 P.H. Kirkegaard & A. Rytter, Vibration based damage assessment of a cantilever using neural networks. *10th International Conference on Experimental Mechanics*, Lisbon, 1994.

B1.6 P.H. Kirkegaard & A. Rytter, Use of neural networks for damage assessment of civil engineering structures. *1st AI-SEA-AI Workshop*, Lausanne, 1994.

B1.7 P.H. Kirkegaard & A. Rytter, Use of neural networks for damage assessment of a steel mast. *IMAC12*, Honolulu, 1994.

B1.8 A. Rytter & P.H. Kirkegaard, Vibrational based inspection of a steel mast. *IMAC12*, Honolulu, 1994.

B1.9 P.H. Kirkegaard & A. Rytter, A comparative study of different vibration based damage assessment techniques. (to be presented at the *IABSE Colloquium*, Bergamo, 1995.

B1.10 P.H. Kirkegaard & R. Brincker, On the optimal location of sensors for parametric identification of linear structures. *Journal of Mechanical Systems and Signal Processing*, Vol. 8, No. 4, 1994.

B1.11 A. Rytter, P. Negro & P.H. Kirkegaard, Vibrational based inspection of a four storey RC-building. (to be presented at the *International Workshop on Structural Damage Assessment using Advanced Signal Processing Procedures*, Pescara, May 29-31, 1995.

B1.12 A. Rytter, M. Krawczuk & P.H. Kirkegaard, An experimental and numerical study of the modal parameters of a damaged cantilever. (to be submitted for publication).

B1.13 P. Andersen & R. Brincker, On the perspectives of using ARMA models in earthquake engineering. Internal Note, Aalborg University.

B2. Modal Analysis Based on Random Decrement Signatures

Project content and status

One of the goals of the project will be to investigate the applicability of the 'Random Decrement Technique' (RDD) for estimation of frequency domain estimates such as a Frequency Response Function (FRF). Investigations of the applicability of parameter estimation based direct on RDD estimates will be an other goal. The goal of these investigations is a formulation of a technique which can be implemented for multi-output systems.

This project started 1.9.1994 with John C. Asmussen as Ph.D. student. A comprehensive information retrieval concerning RDD has been undertaken. Based on the information retrieval it was found, that most of the RDD literature deals with application problems. Only few researchers have considered the theory behind the RDD and implementation of the RDD, respectively. These problems will therefore be considered more closely. Various trig-conditions have been implemented.

In relation to the project the applicability of parameter estimation based direct on RDD estimates has been considered for the estimation of the coefficient of restitution of rocking systems [B2.1].

Plans for 1995

In 1995 work on the implementation of the RDD algorithm will be continued. In order to obtain a robust technique trig conditions, bias problems, and selection of the RDD-window will be considered. The main emphasis will be on lightly damped structures. It is intended that John Asmussen spends 3-4 months at a foreign university in the autumn.

This project will also benefit from the planned visits by Profs. Ibrahim Piombo mentioned in the B1 project.

Participants

John Christian Asmussen, Ph.D. student, Department of Building Technology and Structural Engineering, Aalborg University. From 1.9.1994, financed by the research programme from 1.3.1995.

Rune Brincker, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul Henning Kirkegaard, Assistant Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

B2.1 R. Brincker, M. Demosthenous & G.C. Manos, Estimation of the coefficient of restitution of rocking systems by the random decrement technique. *IMAC12*, Honolulu, 1994.

B3. Fatigue and Crack Propagation

Project content and status

The purpose of this project is to examine crack propagation behavior under dynamic load as well as static load mainly for the building materials steel and concrete, using a crack propagation theory. The project is separated into two parts: dynamic fatigue investigations of metals, and crack propagation in concrete. The main purpose is to verify a newly developed crack propagation formula based on a fracture energy balance.

A test series on metals with the purpose to investigate the dependence of the critical stress intensity factor K_{IC} on the fatigue intensity K_I and a series of fatigue tests have been analyzed using the crack propagation formula. It is shown that crack propagation under fatigue loading depends on the fatigue intensity K_{IC}, which will be further verified by comparing test results with theoretical calculations in 1995. The results have been presented in the report [B3.1].

An investigation of notched cubic test specimens of concrete was carried out in 1994, where snap back was successfully recorded. The results are being analyzed theoretically using the crack propagation formula and the results will be published in a report.

An investigation of concrete under triaxial compression was carried out in 1994. A report on the triaxial test results is under preparation [B3.2].

Some theoretical investigations on notched concrete beams using the crack propagation theory has been carried out. A report is under preparation [B3.3].

Plans for 1995

A test series on metals with the purpose to investigate the dependence of the critical stress intensity factor K_{IC} on the fatigue intensity K_I and a series of fatigue tests and hereby further verifying the results from [B3.1] are prepared and will be carried out in the beginning of 1995. Further development of a digital image system to measure crack propagation will also be undertaken. It is also the plan to investigate crack propagation in welded metal structures on the basis of the same theory, but this project is pending the results from the first part of the project.

At the Department of Structural Engineering, DTU, a test series to investigate the fracture mechanics behavior of concrete under compression is planned in spring 1995. The project is carried out in cooperation with several countries and organized by the RILEM 148 committee. This project is related to to the present research programme.

The studies of crack propgation under variable load will be given priority according to the original proposal.

Participants

Thomas Cornelius Hansen, Ph.D. student, Department of Structural Engineering, Technical University of Denmark. Financed by the research programme from 1.1.1993.

Mogens Peter Nielsen, Professor, Department of Structural Engineering, Technical University of Denmark.

Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

B3.1 T.C. Hansen, Fatigue and crack propagation, Report R316, Department of Structural Engineering, Technical University of Denmark, June 1994.

B3.2 T.C. Hansen, Triaxial tests on concrete, Department of Structural Engineering, Technical University of Denmark, (in preparation).

B3.3 T.C. Hansen & D.H. Olsen, Fracture of Concrete, Department of Structural Engineering, Technical University of Denmark, (in preparation).

C: SELECTED DYNAMIC PROBLEMS

C1. Behaviour of Soil Subjected to Dynamic Loads

Project contents and status

The main purpose of the project is to investigate wave propagation in soil. The problems, which will be studied, will be linked to vibration of machine foundations, heavy traffic, trains etc. These cases are all related to dynamic problems concerning very small strain levels and relative high frequencies. To determine the response of the soil during dynamic loading it is necessary to determine the soil parameters under dynamic conditions. The parameters are Young's modulus, E, the shear modulus, G, and the damping of the material, D. These parameters will be functions of several parameters such as strain level, stress level, void ratio and saturation.

The project started 1.7 1994 with Lars Bødker as Ph.D. student. The project will concentrate on determination of the parameters for different kinds of Danish soils. The goal is to obtain some normalised curves to describe the variation of the three parameters according to strain and stress levels for each of the tested materials. All the test material will be fully saturated and the material will both include cohesive and non-cohesive soils. Laboratory test will be performed to determine the variation of the parameters. The laboratory tests will concentrate on resonant column test .

At the beginning of the project apparatus to determine E at stress states in the interval of 0-100 kPa and different strain levels was present at Aalborg University. The apparatus consists of a exciter table and a vacuum system to vary the stress states. During the tests acceleration at the top and bottom of the specimen will be measured, and from this measurement it is possible to calculate the E-modulus and the damping. From the start of the project and till now the work has been concentrated on extending the present equipment also to measure the G-modulus with bending elements. This is done by creating special pressure heads in which the bending elements is build in. The advantage of this is that it is possible to determine both the E-modulus and the G-modulus in the same specimen. The first test series have been carried out, and the used material is Yoldia clay from Nørre Lyngby in Northern Jutland. The Yoldia clay is used because of co-operation with the LITASEIS-project in which field measurements (seismic measurement) are compared with laboratory measurements.

The limit of the developed apparatus is that it is not possible to vary the strain level for the measurement of G. At Geonor, Oslo, the strain level using bending elements has been determined to be less than 10^{-6}, which normally is considered as the limit below which the G-modulus is assumed to be constant. Therefore, the measured G-modulus using bending elements is named G_{max}. To investigate the variation of the G-modulus with strain level the Drnevich resonant column apparatus is powerful. In this apparatus it is possible to measure both E-modulus and G-modulus at different stress and strain levels. Torsion of the specimen is used to determine the G-modulus, and because of this hollow specimen is used. The hollow specimen is important to get a well-defined strain level. It is planned to buy a Drnevich apparatus in 1995.

Plans for 1995

In the beginning of 1995 Lars Bødker will visit NGI in Oslo for four months. The purpose of the visit is to get familiar with the Drnevich apparatus and to start a test series with the same material used in the already performed tests at Aalborg University. A part of the work at NGI will be to develop a new calibration procedure for the Drnevich apparatus. This is chosen to get a good understanding of the principles in the apparatus and because at NGI they are not convinced of the existing procedure.

The tests at NGI will both be resonant column tests to measure E and G at different strain levels and tests with bending elements to measure G_{max}.

After the visit test series at Aalborg University will be continued with the new Drnevich apparatus with different kinds of soil to describe the variation of E and G.

Participants

Lars Bødker, Ph.D. student, Department of Civil Engineering, Aalborg University. Financed by the research program since 1.7.1994.

Lars Bo Ibsen, Assistant Professor, Department of Civil Engineering, Aalborg University.

C2. Dynamic Response of Coarse Granular Materials to Wave Load

Project content and status

The project is related to the Marine Science and Technology II Programme (EU). The overall objective of the MAST II - program is to develop a rational method for the design of monolithic caisson structures on rubble foundation. The aim is to formulate a general document 'Design Guidelines for Vertical Caisson Breakwaters'. The special contribution from this present project is mainly to provide the soil mechanics part of the design tools. The project contains both theoretical and experimental work. The aim of the experimental work is to determine the characteristic strength and strain properties of non-cohesive soils under static and dynamic loadings. The properties will be investigated in both static and dynamic triaxial apparatus and by dynamic load plate tests. The CD and CU triaxial test will be installed into a new data base which fully developed, as a minimum will contain test with 3 relative densities for each of the selected materials. The material selected for testing must cover the grain fraction from fine sand to coarse gravel. The selected materials are indicated in Table 2.

Table 2: Results of the classification tests for the selected material

	Baskarp No. 15	Blokhus sand	Lund No. 0	Portland 8-16 mm	Portland 16-32 mm
d_{50} mm	0.14	0.17	0.35	12	20.5
$U = d_{60}/d_{10}$	1.78	1.5	2.2	1.56	1.42
d_s	2.644	2.646	2.647	2.642	
e_{max}	0.858	0.834	0.889	0.805	
e_{min}	0.549	0.565	0.524	0.611	

The theoretical work in 1994 has been concentrated on identification of failure modes and formulation of the corresponding bearing capacity formulas for monotonic loading of caisson breakwaters. The outcome of the study is going to be placed in the general document 'Design Guidelines for Vertical Caisson Breakwaters', [C2.1] and [C2.2]. These results have also been used to formulate reliability analyses of monolithic vertical wall breakwaters, [C2.3].

A new constitutive model for friction materials including the concepts of a characteristic line $q/p = M_c$ and an ultimate line $q/p = M_u$ within a general triaxial formulation has been developed [C2.5], [C2.6]. The model only requires 6 parameters: 3 for elastic and elasto-plastic stiffness (κ, λ, G), the slopes M_c and M_u of the characteristic and the ultimate state lines, and the initial ratio between shear and volume strain in a triaxial test. The model is in the format of elasto-plasticity with a generalized form of work hardening, in which the contributions from shear and dilatation are weighted. The model gives a good representation of test data in the loading regime for which is has been investigated [C2.6].

The experimental work carried out in 1994 has been static and dynamic triaxial tests on Baskarp no 15. The tests, CD, $CU_{u=0}$ and dynamic CU tests are run with a constant deformation speed varying from 4 to 100.000 % ph. By studying the basic phenomena in triaxial tests under uniform conditions identical responses of the soil due to static and dynamic loadings have been discovered. The static and dynamic responses of sand can be explained by the characteristic state and the strength of sand under undrained conditions is found to be controlled by the drained failure condition both for static and dynamic loadings, see [C2.4]. The static and dynamic tests has been reported in [C2.4]. For Blokhus sand and Lund No. 0 these test series have been carried out previously, and presently the tests are being installed into the data base. In order to perform static triaxial tests on the coarse gravel (Portland 8-16 mm and Portland 16-32 mm) a new 'large' triaxial apparatus has been developed and constructed. This new triaxial apparatus is identical to the apparatus on which the tests on sand (Baskarp, Blokhus and Lund) have been performed . The large triaxial cell allowed triaxial testing of 250 mm high cylindrical specimens with a diameter of 250 mm. This dimension of the specimen is a necessary consequence of the grain size. The production and installation of the new triaxial apparatus has been executed and CD tests on Portland 8-16 mm is started.

Plans for 1995

All the failure modes described in [C2.1] are kinematically admissible but not necessarily admissible which means that the presented bearing capacities may be on the unsafe side. To study the uncertainties introduced by the bearing capacity formulas the failure modes described in [C2.1] will be analysed by the finite element program ABAQUS.

Work on the constitutive model for friction materials will be continued. In particular development of numerical algorithms for implementation into a finite element program will be considered. Contact has been established with Prof. Rene de Borst and Arend E. Groen at the Technical University in Delft, and a visit by A.E. Groen in 1995 has been planned.

The CD tests on Portland gravel will be continued. 3 test series with different relative density is planed on Portland 8 - 16 mm and Portland 16-32 mm. . Dynamic triaxial tests on Lund and Baskarp sand , and static triaxial CD and CU tests on doublet height specimen will be performed. The tests program will be planed in such a way that the tests can support the the characteristic state models presented in [C2.4]-[C2.6].

Participants

Hans F. Burcharth, Professor, Department of Civil Engineering, Aalborg University.

Lars Bo Ibsen, Assistant Professor, Department of Civil Engineering, Aalborg University.

Steen Krenk, Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Marianne Borup and Jette Hedegaard, M.Sc. thesis students, Aalborg University.

Publications and conferences

C2.1 H.F.Burcharth & L.B.Ibsen : Response of Rubble Foundation to Dynamic Loading, *Proceedings of International workshop on Wave Barriers in Deepwaters*, Port and Harbour Research Institute Yokosuka, Japan Jan 10 - 14 , pp 402 - 417, 1994

C2.2 L.B.Ibsen: 5 Design Level 1 , Feasibility. Part of Design Guidelines for Vertical Caisson Breakwaters. version 1.1 November 4, 1994.

C2.3 C.S.Sørensen, L.B.Ibsen, A. Hansen & K.P.Jakobsen: Bearing Capacity of Caisson Breakwaters on Rubble mounds. Version 2 November 14, 1994

C2.4 L.B. Ibsen, Static and dynamic strength of sand, (submitted to the *Eleventh European Conference on Soil Mechanics and Foundation Engineering*, Copenhagen, 29 May - 1 June, 1995).

C2.5 S. Krenk, M. Borup & J. Hedegaard, A characteristic state model for sand. Engineering Mechanics Paper No. 24, Aalborg University, December 1994, (submitted to the *Eleventh European Conference on Soil Mechanics and Foundation Engineering*, Copenhagen, 29 May - 1 June, 1995).

C2.6 M. Borup & J. Hedegaard, *Characteristic State Modelling of Friction Materials*, M.Sc. Thesis, Aalborg University, January 1995.

C3. Dynamics of Sports Stadiums

Project content and status

In the current design of sports stadiums dynamic effects constitute an important part. The dynamic loads are mainly from wind and spectator movement. In both cases a good representation of the dynamic properties of the stadium as well as the load are necessary. Spectator motion can cause various types of periodic or transient dynamic loads. The periodic loads are mainly due to jumping, dancing, walking, body rocking and the special "wave" motion, seen at football matches. Transient loads primarily result from single impulse loads, such as jumping or falling from elevated positions. The response to these loads are of primary interest.

The purpose of this project is to develop a spectator load model that gives a realistic representation of the dynamic impulse or force and its spatial distribution. In this connection the validity of typical dynamic design assumptions for sports stadiums regarding eigenfrequencies, mechanical damping, mode shapes and amplitudes, will be investigated.

The main idea is to base the spectator load model on the impulses exerted by spectators on the structure. This may be done if the time period t_p of the individual impulse is small compared to the vibration eigenperiod T_n of the structure. One reason for specifying a load impulse is that the load function is very dependent on the type of motion and the interacting bodies, whereas the impulse corresponds to the time integral of the load function, which is independent of the shape of the function.

A preliminary parametric study of the accuracy of impulse analysis in structural dynamics has been performed for single degree of freedom systems. It has been found that impulse analysis can be used by introduction of a simple correction factor for time ratios t_p/T_n up to about 1. The possibility of using (subdivided) impulse analysis for larger time ratios still remains to be investigated. For t_p/T_n ratios greater than about 4 a quasi static response will probably be sufficient.

A small 80cm×80cm measuring platform has been cast in concrete and installed with 4 force transducers. The platform is used to measure the vertical load from one person performing different in situ movements, such as jumping. The person is also equipped with an accelerometer at the waist to monitor the movements.

In connection with the project a visit has been made to Dr. Sven Ohlson, Unit for Dynamics in Design, Chalmers University of Technology, who has been working with man-induced dynamic loading.

Plans for 1995

The theoretical part of the project will include the following. The possibility of using simplified impulse analysis even for large t_p/T_n ratios will be investigated. Finite element analysis will be used to compare the structural response due to the exact load function with the structural response due to the equivalent (half-sine) impulse load. Finite element analysis will be used to make comparisons with the experimentaly determined dynamic mode shapes, eigenfrequencies and mechanical damping coefficients. It is the aim to formulate a simple impulse based recommendation for loads on grandstands and simmilar structures, as an alternative to the current use of static loads.

The experimental part of this project will be carried out in two main phases, one in the laboratory and another at a grandstand at a rock concert or a football match. In the laboratory there will be three stages. In the first stage the body motion and the load as a function of time will be measured on the small load platform mounted on a stiff laboratory floor for jumping and a 'wave' motion. This will be performed in december 1994 and january 1995. In the second stage the load platform will be mounted on a simple beam/plate structure and the measurements repeated on the beam both on and off the platform. In the third stage the effect of multiple persons on the beam will be measured. The beam will be analysed using experimental modal analysis, determining eigenfrequencies, mode shapes and damping coefficients. The second and third part will be performed during the first half of 1995. At the grandstand measurements will be performed for one person jumping, for multiple persons jumping and for a real situation either a concert or a football match. This second phase will be performed at a convenient time during 1995.

Jeppe Jönsson's employment at the Department of Building Technology and Structural Engineering ends in 1995. The project plans to employ Jeppe Jönsson the last 3 months of 1995 and 3 months in 1996. He will analyse experimental results, perform finite element analyses and develop a load model for design of spectator loads.

Participants

Lars Pilegaard Hansen, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Jeppe Jönsson, Assistant Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

C3.1 J. Jönsson & L. Pilegaard Hansen, Man-Induced Vibrations, *Dynamics of Structures, A workshop on dynamic loads and response of structures and soil dynamics*, Aalborg University, Denmark, September 14-15, 1994.

C4 Dynamic Measurements on the Frejlev-Mast

Project content and status

The purpose of the project is to evaluate the system identification programmes from the B.1 project on a real structure. This task will be carried out in this project in 1995 and the spring of 1996. The aim of this project is to make full-scale measurements on the Frejlev-mast which is a 200 meter high guyed steel mast located 10 km from Aalborg. Both the C++ programme and the programmes in the STDI toolbox will be evaluated. One of the goals will be to investigate the uncertainties of the modal parameters and mode shapes obtained by a practical application of time series models such as multi channel ARMA-models. Especially, problems concerning model reduction and separation of closely-spaced modes will be investigated.

The investigations of the Frejlev-mast will in part be done in cooperation with the consultant company Rambøll, Hannemann & Højlund, who are particularly interested in the forces in the cables. Therefore, an additional purpose of the project is to measure the strains in the cables.

Plans for 1995

In January-February 1995 the mast will be instrumented in order to measure strains in the cables. However, before the mast can be instrumented tests with the instrumentation and data acquisition equipment have to be performed in the laboratory. Also in January-February 1995 plans for the vibration measurements will be made. It is assumed that accelerometers, cup-anemometer and wind-vane can be mounted on the mast in Marts-April 1995. This means that preliminary tests with the strain-gauges and the vibration measurement equipment can be done during the first half of 1995. After the preliminary tests it is assumed that the instrumentation and data acquisition system have to be improved and corrected. This implies that monitoring of the Frejlev-mast will take place doing the autumn 1995.

Analysis of measurement data will be done from the start of the project. A final report will be finish in the spring of 1996.

Participants

Palle Andersen, Ph.D. student, Department of Building Technology and Structural Engineering, Aalborg University.

Rune Brincker, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

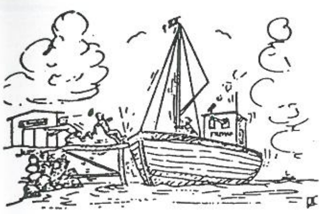
Poul Henning Kirkegaard, Assistant Professor, Department of Building Technology and Structural Engineering, Aalborg University.

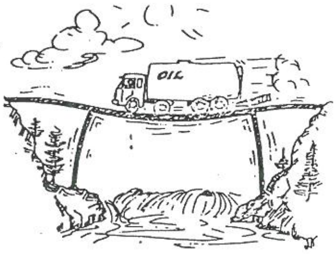
Aalborg, 27 February, 1995.

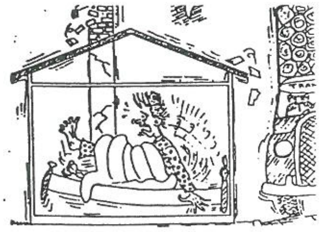
Steen Krenk

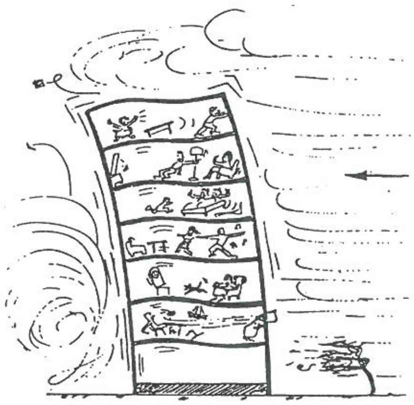
APPENDIX I

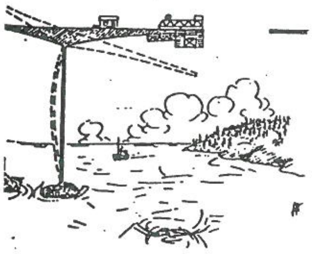
Progress Report, 1995

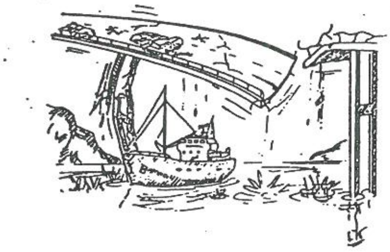


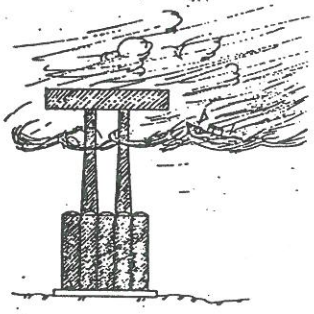












DYNAMICS OF STRUCTURES

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PROGRESS REPORT 1995

Contents

1. Introduction

Dynamics of Structures is a research programme sponsored by the Danish Technical Research Council. The programme started in 1993 and will continue to the end of 1997. It is a cooperative effort of the Department of Building Technology and Structural Engineering and the Department of Civil Engineering at Aalborg University and the Department of Structural Engineering at the Technical University of Denmark (until the end of 1995).

The purpose of the programme is to conduct research and to provide research education and results relating to dynamic loads and response of structures and foundations. Characterization and modelling of materials under time varying loads are also parts of the research programme. The research will develop and use both analytical, numerical and experimental methods.

The problem areas dealt with in the research programme are:

- Analysis of structures
- Wind and wave loads
- Soil mechanics
- System identification
- Damage detection
- Fatigue and crack propagation
- Man induced vibrations
- Experimental methods

This progress report for 1995 is organized according to the structure of the original proposal with the following project:

A. BASIC THEORY

- A1 Mode shape and reduced base techniques
- A2 Wind loads on structures
- A3 Dynamic response of structures with stochastic properties and excitation

B. EXPERIMENTAL TECHNIQUES

- B1 Damage detection in structures under random loading
- B2 Modal analysis based on the random decrement techniques
- B3 Fatigue and crack propagation

C. SELECTED DYNAMIC PROBLEMS

- C1 Behaviour of soil subjected to dynamic loads
- C2 Dynamic response of coarse granular materials to wave loads
- C3 Dynamics of sports stadiums

C4 Dynamic measurements on the Frejlev mast

2. General Status

As described in the progress report 1993 - 94 the structure of the research programme confirms closely with that of the original proposal. Project C1 has been adjusted a little, and project A3 now covers the activities of an AAU - financed Ph.D. student relating to the subject. In 1995 the research programme has financed 5 Ph.D. students so a total of 6 Ph.D. students are working in the programme.

The expenses (excl. overhead) for the research programme in thousands of DKr. in 1995 are given in table 1.

Project	Ph.D. student	Salary	Other expenses	Total
A1	Steffen Vissing	185	145	330
A2			2	2
A3	Poul S. Skjærbæk		62	62
B1	Palle Andersen	315 NOTE 1	128	443
B2	John Asmussen	168	141	309
B3	Thomas Cornelius	101 NOTE 2	111	212
C1	Lars Bødker	206	335	541
C2		257 NOTE 3	117	374
C3				0
C4			23	23
Secretariat		57	34	91
Total		1289	1098	2387

NOTE 1: Includes also salary for Poul Henning Kirkegaard
NOTE 2: Ph.D. expenses for half of the year paid in 1994
NOTE 3: Salary for Finn Rosendahl Jacobsen

Table 1. Expenses for the research programme in 1995

Many of the projects have established international contacts as indicated in the sections in chapter 3.

A workshop similar to the one in 1994 was announced in the autumn of 1995 but was cancelled as only 5 (external) persons have signed up. A workshop is planned in the autumn of 1996 and an effort will be made to increase the number of external participants.

The programme leader, Steen Krenk, has left Aalborg University and is now working at Lund University in Sweden but has still connection to the research programme. The program leader from autumn 1995 is Lars Pilegaard Hansen, Aalborg University.

3. Description of Projects

3.1 Project A1. Mode Shape and Reduced Base Techniques

Content and status

The project deals with numerical techniques for reduction and subsequent eigenvalue analysis of models from structural analysis.

The main focus has been on the development of the combination of a Lanczos reduction technique for linear and quadratic eigenvalue problems, and a generalized algorithm of QR-type for the final
eigenvalue analysis. A modified format, using a tridiagonal matrix and a diagonal matrix with ± 1 elements, is introduced for indefinite problems that occur e.g. in connection with complex eigenvalues in damped oscillations of structures. The generalized QR-algorithm extracts the complex eigenvalues from this format by use of real arithmetic.

In 1995 the algorithms have been completed, and finite element routines have been developed, extending the MATLAB-based finite element program developed at AAU (Aalborg University) to dynamic analysis. The work has been presented at 'Svenska Mekanikdagar' and ' 8'th Nordic Seminar on Computational Mechanics '. Research assistant Hilda van der Veen from the Technical University of
Delft has visited the project for a week and presented related work. A Ph.D. thesis by Steffen Vissing entitled 'A generalized Lanczos-QR technique' has been completed, and submitted at the end of the year.

Participants

Steffen Vissing, Ph.D. student, Department of Building Technology and Structural Engineering, Aalborg University.

Steen Krenk, Professor, Division of Mechanics, Lund Institute of Technology, Lund University, Sweden

Publications

A1.1 S. Vissing and S. Krenk: *A generalized Lanczos-QR technique*. Paper 1.4, Svenska Mekanikdagar, Lund, May 31 - June 2, 1995.

A1.2 S. Vissing and S. Krenk: *A generalized indefinite QR algorithm*. Paper A.6.2, 8'th Nordic Seminar on Computational Mechanics, Göteborg, November 16 - 18, 1995.

A1.3 S. Vissing: *A generalized Lanczos-QR technique*. Ph.D. thesis, pp. 149, Department of

Building Technology and Structural Engineering, Aalborg University, December, 1995.

3.2 Project A2. Wind Loads on Structures

Content and status

Two problems of structural wind loads have been considered: turbulent buffeting loads and vortex induced vibrations.

In engineering practice the spatial correlation is usually represented by an exponential function of separation distance. For large structures or high frequencies this representation overestimates the resulting wind load, because the correlation of along-wind fluctuations changes from positive to negative at sufficient distance. A simple theoretically founded improvement on the exponential format has been derived, reducing the resulting load on long slender structures with about 25\% in the high frequency range. The results were presented at the IUTAM Symposium on Nonlinear Stochastic Mechanics, organized in Trondheim by Arvid Naess with S Krenk as co-chairman and proceedings editor.

Michael Kleiser visited AAU from Munich financed by the EU Human Mobility Programme and worked on vortex-induced vibrations. The work included an analysis and reformulation of a recent
model of single-oscillator type.

Plans for 1996

Wind

It is planned that S. Nielsen and S. Krenk work together on simplified models for vortex-induced vibrations, aiming at producing an alternative to the current Eurocode proposal for practical design. Recent data seem to indicate that the criteria for occurrence of vortex-induced vibrations need improvement, and also improved estimates of the maximum amplitude and its dependence on e.g. the wind turbulence are desirable. In addition an attempt will be made to simplify a recently published model for representation and simulation of turbulence in natural wind, and to derive relevant parameters from balance of the energy dissipation.

Water

A project entitled Active Vibration Control of Monopile Platforms will be initiated. At the exploitation of marginal fields in the Jutlandian sector of the North Sea monopile platforms have proved to be beneficial. In the original concept the platform was designed to water depths of 35-50 m, and was assumed to be operated unmanned. Vibrations of the structure under these conditions are unimportant in all cases. However, in later applications the concept is under consideration for a water depth up to 75 m, and the platforms are assumed to be manned. In this case significant dynamic amplification can arise in comparison to the quasi-statical response. The project, which is proposed together with Rambøll, Esbjerg, is aimed at developing an active vibration system for reduction of wave induced oscillations.

The system is based on control of the boundary layer flow, and hence of the loading on the cylinder. The wave load consists of a drag component and an inertial component. Only the drag component is under consideration. Normally, the drag coefficient is 0.6-0.9 for a circular cylinder. For a sharp edge body the drag coefficient can amount to 1.5-2.0. The cylinder will act effectively as a sharp-edged body, if the boundary layer is forced to separate before the natural separation points. The separation of the boundary layers will be ensured by blowing air from inside the cylinder whenever appropriate.

The idea is to ensure a large drag coefficient, when the velocity of the structure is opposite to that of the fluid. In this case the boundary layers are blown away. When the velocity of the structure and the fluid are unidirectional, no forced separation is impinged on the boundary layers. The velocity of the structure is measured by accelerometers on the platform, and the velocity of the boundary flow relative to the structure is measured by an ultrasonic velocity meter, attached to the structure. The advantage of the principle compared to other active vibration arrangements is that the power for vibration reduction is supplied primarily from the fluid itself. Only the power for blowing the boundary layers off needs to be supplied externally.
The applicability of the principle will be demonstrated by a series of tests in January and February 1996, in stationary flow and regular waves. The optimal control of air blowing has also been recognized. During the month of April a final test with a further optimized test setup will be performed.

Publications

A2.1 S. Krenk: *Wind field coherence and dynamic wind forces*. IUTAM Symposium on Advances in Nonlinear Stochastic Mechanics,Trondheim, July 3-7, 1995. (Proceedings published by Kluwer Academic Publishers, 1996)

A2.2 M. Kleiser, S.R.K. Nielsen and J.D. Sørensen: *Vortex-induced vibrations - Sensitivity and applicability of life-oscillator models*. (Manuscript), Department of Building Technology and Structural Engineering, Aalborg University, 1995.

Participants

Steen Krenk, Professor, Division of Mechanics, Lund Institute of Technology, Lund University, Sweden

Søren R.K. Nielsen, Reading Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul H. Kirkegaard, Ph.D., Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

3.3 Project A3. Dynamic Response of Structures with Stochastic Properties and Excitation

Content and status

From March 1995 Poul S. Skjærbæk has been engaged in developing a method for localizing damages in severely damaged buildings exposed to earthquake. The prerequisite of the method is that the building has been instrumented so that the surface ground acceleration and the top-storey displacements are measured, which is the most applied setup in practice. Based on this input-output relationship it is further assumed that at least the two lowest time-varying smoothed circular eigenfrequencies, $\omega_1(t)$ and $\omega_2(t)$, can be identified. The damage of a certain substructure or beam element is assumed to be reflected by the relative reduction of the stiffness matrices of such substructures. An algoritm for localization of the indicated damage measures has been derived.

The applicability of the method has been demonstrated using simulated data obtained by the SARCOF program (Stochastic Analysis of Reinforced Concrete Frames), see [A3.1] and [A3.9].

The problem of identifying the smoothed 1st circular eigenfrequencies,$\omega_1(t)$, which form the basis for the so-called maximum softening damage indicator, was investigated using discrete wavelet anlysis, see [A3.2] , and using short-time Fourier transform, continuous wavelet transform and Wigner-Ville distribution, see [A3.4]. These papers were written in June-August 1995 during a 3-month stay by Ray Micaletti in Aalborg, financed by the research programme.

The cooperation on stochastic response of uncertain structures exposed to random loads with Professor A. S. Çakmak, Princeton University, and Assistant Professor H.U. Köylüoğlu, was further developed during the year. S.R.K. Nielsen visited Princeton Universty for a fortnight in January 1995, and H.U. Köylüoğlu visited Aalborg University for one week in August 1995. During a year a paper on faster Monte-Carlo simulation schemes for hysteretic structures, based on an extension of the Ermak-Allen algoritm from molecular dynamics, was suggested, see [A3.3]. An Ermak-Allen type of algoritm was also suggested for the integration of moment equations of geometrically non-linear structures, see[A3.5]. The capabilities of a previously developed model for analysis of RC-structures, based on sequential updating, was further investigated,and it was demonstrated that the localization of damage is highly dependent on the frequency contents of the excitation, see [A3.6]. A method for dealing with the buckling load and reliability of structures with uncertain properties based on stochastic finite elements was also derived, see [A3.7]. Finally, some further results for a previously devised perturbation method for dealing with structures with random properties was addressed, see [A3.8].

Plans for 1996

Poul Skjærbæk is visiting the Department of Civil Engineering and Operations Research, Princeton University as a guest of Professor A. S. Çakmak during the period January 1 to June 15. During the stay he is supposed to improve the damage localization method for severely damaged RC-structures by introducing auxiliary measurements providing both time-averaged circular eigenfrequencies and mode shapes. Besides, he will deal with the identification of such quantities on real time measurements.

The developed localization procedure has only been tested with simulated data optained by the SARCOF FEM program. The applicability of this program has only been demonstrated for predicting the non-linear displacement response of RC-frames, whereas the capability for predicting the damage development in elements and substructures is unknown. For this reason a series of preliminary tests will be performed at the return of Poul Skjærbæk on two 6-storey 2-bay
reinforced concrete frames in the scale 1:6 exposed to earthquake loading.

Finally, a new project entitled Dynamic Amplification Factors in Relation to Traffic Loads at Reinforcement Projects on Minor Highway Bridges will be initiated. The background of the project is, that during the recent years it has been nescessary to upgrade smaller highway bridges to heavier loads, partly because heavy trucks are driving with higher velocities, and partly because the highway authorities are inclined to allow transportation of especially heavy goods over a larger
part of the highway net. This calls for reinforcement of the bridges in most cases. To keep the expenses for this reinforcement project at a minimum it is necessary to perform accurate calculations of the dynamic amplification factor, so its magnitude is neither over- nor underestimated.

The critical load scenario occurs, when two heavy vehicles are passing the bridge simultaneously. According to Danish standards these two heavy vehicles are made up of a "lighter" vehicle (up to 50 ton) and a heavier vehicle (100-150 ton). For both vehicles a dynamic amplification factor of 1.25, acting simultaneously, is assumed, which is an expensive generalization for reinforcement projects, and emphasizes the need for a better specification of the dynamic reinforcement for highway bridges. Since the bridges are relatively small, these are assumed to respond quasi-statically. Only the vehicle dynamics is considered. The highway irregularities are modelled stochastically, and the obtained amplification factors are interpreted as a random variable with distribution depending on the speed of the opposite approaching vehicles, the variability and wave length distribution of the highway surface, and the dynamics of the involved vehicles.

The primary gain of the project is a considerable reduction of the expenses of such reinforcement projects. At present 100 existing highway bridges are under consideration for upgrading to heavier loads.

Participants

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H.U. Köylüoğlu, Ph.D., Assistant Professor, College of Arts and Sciences, Koc University, Istinye, 80860 Istanbul, Turkey.

Ib Enevoldsen, Ph.D., Rambøll, Nørregade 7A, 1165 Copenhagen K. Financed by the Danish Technical Research Council.

Publications

A3.1 P.S. Skjærbæk, S.R.K. Nielsen & A. S. Çakmak: *Damage Localization of Severely Damaged RC-Structures based on Measured Eigenperiods from a Single Response.* Structural Reliability Theory, Paper No. 149, Aalborg University (to be presented at the Localized Damage Conference, Fukuoka, Japan, June 1996).

A3.2 R.C. Micaletti, A. S. Çakmak, S.R.K. Nielsen & P.H. Kirkegaard: *Construction of Time-Dependent Spectra using Wavelet Analysis for Determination of Global Damage.* Structural Reliability Theory, Paper No. 147, Aalborg University (to be presented at the Noise and Vibration Conference , Leuven, Belgium, September 1996).

A3.3 H.U. Köylüoğlu, S.R.K. Nielsen & A. S. Çakmak: *A Faster Simulation Method for the Stochastic Response of Hysteretic Structures subject to Earthquakes.* Structural Reliability Theory, Paper No. 127, Aalborg University (submitted to Earthquake Engng. Struct. Dyn.).

A3.4 P.H. Kirkegaard, S.R.K. Nielsen, R.C. Micaletti & A. S. Çakmak: *Identification of a Maximum Softening Damage Indicator of RC-Structures using Time-Frequency Techniques.* Structural Reliability Theory, Paper No. 146, Aalborg University (to be presented at the EURODYN'96 Conference , Florence, Italy).

A3.5 H.U. Köylüoğlu, S.R.K. Nielsen & A. S. Çakmak: *Approximate Forward Difference Equations for the Lower Order Non-Stationary Statistics of Geometrically Non-Linear Systems subject to Random Excitation.* Structural Reliability Theory, Paper No. 131, Aalborg University. To appear in Proc. 3rd. Int. Conf. Stochastic Struct. Dyn. , San Juan, Puerto Rico, January, 1995 (in press). Also in review for the J. Int. Nonlinear Mech.

A3.6 H.U. Köylüoğlu, S.R.K. Nielsen, J. Abbott & A. S. Çakmak: *Local and Modal Damage Indicators for Reinforced Concrete Shear Frames subject to Earthquakes.* Structural Reliability Theory, paper No. 145, Aalborg University (submitted to J. Eng. Mech., ASCE).

A3.7 H.U. Köylüoğlu, S.R.K. Nielsen & A. S. Çakmak: *Uncertain Buckling Loads.* Structural Reliability Theory, paper No. 141, Aalborg University (to appear in Bulletin of the Technical University of Istanbul).

A3.8 H.U. Köylüoğlu, S.R.K. Nielsen, & A. S. Çakmak: *Solution Methods for Structures with*

Random Properties subject to Random Excitation. Proc. ASCE Specialty Conf. ,Ed. Stein Sture, Colorado, June 1995, pp. 1131-1134.

A3.9 P.S. Skjærbæk, S.R.K. Nielsen & A. S. Çakmak:*Assessment of Damage in Seismically Excited RC-Structures from a Single Measured Response*. Fracture and Dynamics, Paper No. 64, Aalborg University (to appear in Proc.14th Int. Modal Analysis Conf., Michigan, February 1996).

3.4 Project B1. Damage Detection in Structures under Random Loading

Content and status

In the period from January 9 to May 31, 1995 Palle Andersen was on maternity leave from his Ph.D study. In the end of April 1995 professor Bruno Piombo from Torino, Italy, visited the participants of the project at Aalborg University. During this visit the use of Auto-Regressive Moving Average Vector (ARMAV) models for discrete-time modelling of structural systems was discussed.

From June 1 to October 1, 1995 Palle Andersen visited Prof. G.C. Manos, Department of Civil Enginering at Aristotle University of Thessaloniki, Greece. During this visit he was attached to the EU founded EURO SEIS-Test programme. His job was primarly system-identification of EURO SEIS-Test structure. The results of the work are described in [B1.1], which is to be completed in the spring of 1996. During the visit a hybrid identification routine, combining the accuracy of the ARMA model with a high-speed unbiased FFT-estimation of sampled covariance functions was developed. This hybrid approach has made it possible, by means of a univariate ARMA model, to estimate all modal parameters, including scaled modeshapes. In [B1.2] the approach has been tested on offshore data supplied by Intervep A.S.

From October 1 to December 31, 1995 Palle Andersen's work has mainly concerned time series modelling using different state space realizations, implementation of different algorithms for on-line and off-line calibration of full-polynomial ARMAV models, see [B1.3]. These algorithms are now a part of the STDI toolbox. Both on-line and off-line algorithms have been used for system-identification of different systems. They have shown promissing results in the case of systems containing closely space modes, see [B1.4], [B1.5] and [B1.6]. The software of the STDI toolbox has also been used in the development of the publications [B1.7], [B1.8] and [B1.9].

Plans for 1996

The more practical aspects of damage assessment will be considered. In relation to this a large number of measurements of a 20 m. laboratory lattice steel mast is planned. During the measuring period damages will be artificial introduced. The measurements will be spread over a long period, in order to make the environmental conditions change significantly. This will result in disturbance of the estimated modal parameters. It is the idea to filter this disturbance out using an on-line regression analysis. The detection of damages will be based on modal parameters using the software of the STDI toolbox. The localization and quantification of the damages will be based on already well proved methods.

The cooperation with G.C. Manos and the EURO SEIS-test project will be continued. This cooperation will probably result in further analysis of earthquake excited structures. Also the cooperation with Intervep A.S. is planned to continue. This company has proved to be a valuable source in obtaining response data from ambient excited offshore structures.

The work with on-line calibration algorithms will be continued and be related to the project A.3, and the work with the STDI toolbox will be completed. The work is now concentrated around the development of a user-friendly graphical interface.

Participants

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Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul Henning Kirkegaard, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications

B1.1 J.C. Asmussen, P. Andersen, R. Brincker & G.C. Manos : *Identification of the EURO SEIS Test Structure*, 1996. Fracture & Dynamics No. 76, Aalborg University.

B1.2 R. Brincker, P. Andersen, M.E. Martinez & F. Tallavó : *Modal Analysis of an Offshore Platform using Two Different ARMA Approaches*. 14th International Modal Analysis Conference, February 1996, Dearborn, Michigan USA. Fracture & Dynamics No. 66, Aalborg University.

B1.3 P. Andersen, R. Brincker & P.H. Kirkegaard:*Theory of Covariance Equivalent ARMAV Models of Civil Engineering Structures* 14th International Modal Analysis Conference, February 1996, Dearborn, Michigan USA. Fracture & Dynamics No. 71, Aalborg University.

B1.4 P.H. Kirkegaard, P. Andersen & R. Brincker: *Identification of the Skirt Piled Gullfaks C Gravity Paltform using ARMAV models* 14th International Modal Analysis Conference February 1996, Dearborn, Michigan USA.Fracture & Dynamics No. 69, Aalborg University.

B1.5 P.H. Kirkegaard, P. Andersen & R. Brincker: *Identification of Civil Engineering Structures using Multivariate ARMAV and RARMAV models.* International Conference of Engineering Systems, March 27 - 29, 1996, Swansea, Wales. Fracture & Dynamics

No.70, Aalborg University.

B1.6 P.H. Kirkegaard, P. Andersen & R. Brincker: *Identification of an Equivalent Linear Model for a Non-Linear Time-Variant RC-Structure.* International Workshop on Structural Damage Assessment using Advanced Signal Processing Procedures, May 1995, Pescara, Italy. Fracture & Dynamics No. 68, Aalborg University.

B1.7 Sørensen, N.B. & P.H. Kirkegaard: *Dynamic Parameters as Damage Indicators for Fibre Reinforced Matrices*. Nordic Concrecte Research, Publication NO. 17, Vol. 2, 1995.

B1.8 Sørensen, N.B. & P.H. Kirkegaard: *A Comparative Evaluation of Three Damage Indicators in Flexural Fatigue of CRC matrics.* Submitted to Experimental Mechanics, SEM , 1995.

B1.9 Rytter, A., P. Negro & P.H. Kirkegaard: *On-Line Estimation of Stiffness Matrices during a Pseudo-Dynamic Test*, Joint Research Center, Ispra, Italy, 1995.

3.5 Project B2. Modal Analysis Based on Random Decrement Signatures

Content and status

The project is carried out as a Ph.D.-project. The project will be finished according to the original project. The aim of this project is to investigate the applicability of the random decrement technique for estimation of modal parameters.

During 1995 the Ph.D.-student John Christian Asmussen has spent 4 months at the University of Thessaloniki, Greece. The aim was identification of a 5 storey model structure used in a project on eartquake financed by the EEC. The work is reported in [B2.4].

The applicability of the random decrement technique for identification of structures from ambient response has been investigated with good results, see [B2.2]. Furthermore, the problem of identification of structures to general forces has been investigated theoretically and on simulated data, see [B2.3].

The problem of estimating frequency response functions by random decrement has been investigated, see [B2.1]. The work is based on simulated data. The results from the random decrement technique has been compared with the traditional method based on Fourier transformations. The investigations show that the random decrement technique has some advantages. Therefore, this work will be continued in 1996 with respect to the speed and quality of different approaches.

Plans for 1996

In the first part of 1996 a laboratory bridge model will be built. The purpose of the work with the bridge model is: to get experience and to produce software to measure the response of a bridge. Later in this project the plan is to measure and analyse the response of a real bridge. Furthermore, the influence of the vehicle load will be investigated. The bridge model is under construction, and an initial modal analysis of the response of the bridge by both Random Decrement and Fourier transforms will be performed. This work is planned to be presented at the ISMA 21 conference, Leuven Belgium, in September 1996.

Another work in the first part of 1996 is estimation of covariance functions of multi degree-of-freedom systems. The purpose of this work will be a comparison of speed and quality of two different approaches: random decrement and Fourier transformations.

During the summer of 1996 Professor Ibrahim, Old Dominion University Virginia USA, will wisit Aalborg University. The plans for this are investigation of a vector formulation of the trig conditions. This new approach will be tested on both simulated and real data of an offshore platform. This work is planned to be presented at the 15th IMAC Conference in February 1997.

Participants

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Publications

B2.1 J.C. Asmussen & R. Brincker: *Estimation of Frequency Response Functions by Random Decrement*. Proceedings of the 14th International Modal Analysis Conference, February 1996, Dearborn, Michigan, USA.

B2.2 J.C. Asmussen, S.R. Ibrahim & R. Brincker: *Random Decrement and Regression Analysis of Traffic Responses of Bridges*. Proceedings of the 14th International Modal Analysis Conference, February 1996, Dearborn, Michigan, USA.

B2.3 S.R. Ibrahim, J.C. Asmussen & R. Brincker. *Modal Parameter Identification from Responses of General Unknown Inputs*. Proceedings of the 14th International Modal Analysis Conference, February 1996, Dearborn, Michigan, USA.

B2.4 J.C. Asmussen, P. Andersen, R. Brincker & G.C. Manos: *Identification of the EUROSEIS Test Structure*. Fracture & Dynamics No. 76, Aalborg University.

3.6 Project B3. Fatigue and Crack Propagation

Content and status

The project is separated into two fields. The first field concerns dynamic fatigue investigations of metals and the second field is concerning crack propagation in concrete.

The main purpose is to verify a newly developed crack propagation formula.

A test series on metals with the purpose to investigate the dependence of the critical stress intensity factor K_{IC} on the fatigue intensity K_I and a series of fatigue tests are analysed using the crack propagation formula. It is shown that crack propagation under fatigue loading depends on the fatigue intensity factor K_{IC}. The results have been presented in a report published in 1994, see [B3.1].

A test series on high strength steel with the purpose to investigate the dependency of the critical stress intensity factor K_{IC} on the fatigue intensity K_I and a series of fatigue tests are hereby further verifying that the results from the project carried out in 1994 [B3.1] were carried out during 1995. A report will be published [B3.4].

An investigation of concrete under triaxial compression was carried out in 1994. A report on the triaxial test results has been performed [B3.2].

An investigation of crack propagation in welded metal structures has been performed.The crack propagation formula has been used to predict the crack growth in welded joint test specimens and welded center cracked test specimens. A report is under preparation and will be published in 1996 [B3.5.].

An investigation on notched concrete beams has been carried out using the crack propagation formula. The results will be presented in a report which will be published in 1996 [B3.3].

Both the results from the concrete investigations and the results from the metal investigation are very promising. It seems likely that the crack propagation formula in a very simple way is able to predict fracture in general for various materials under varying loading conditions.

Plans for 1996

The project was finished in December 1995. Some remaining work on the reports in the project will be carried out and the reports will be published during 1996.

Participants

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Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Rune Brincker, Associate Professor, Department of Building Technology and Structural

Engineering, Aalborg University.

Lise Gansted, Assistant Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications

B3.1 T.C. Hansen: *Fatigue and Crack Propagation*, R316. Department of Structural Engineering, DTU, 1994.

B3.2 T.C. Hansen: *Triaxial Tests on Concrete*, R319, Department of Structural Engineering, DTU, 1995.

Pending:

B3.3 T.C. Hansen and D.H. Olsen: *Fracture of Concrete*, Department of Structural Engineering, DTU, 1996.

B3.4 T.C. Hansen: *Fatigue in High Strength Steel*, Department of Structural Engineering, DTU, 1996.

B3.5 T.C. Hansen: *Fatigue in Welded Connections*, Department of Structural Engineering, DTU, 1996.

3.7 C1. Behaviour of Soil Subjected to Dynamic Loads

Content and status

The project deals with determination of the elastic properties of different kinds of soils, such as Young's modulus, shear modulus , Poisson's ratio, and damping of both frictional soils and cohesive soils. These parameters are required in analyses of foundations exposed to dynamic loadings, resulting from high speed trains, earthquakes and engine foundations where small strain deformations occur. These parameters will be determined experimentally in the laboratory by tests at very small strain levels partly by torsion and longitudinal resonant column tests and partly by tests with piezoceramic bender elements. The objective is to obtain a large data base for the elastic parameters for frictional and cohesive soils. Beyond the actual research program the project also entails a close cooperation with the LITASEIS project which is an international and interdisciplinary project dealing with field- and laboratory measurements of the dynamic properties of soil. The LITASEIS project is sponsored by EU.
At present new laboratory equipment has been developed to be used in conventional test set-ups at the Soil Mechanics Laboratory at Aalborg University by means of bender elements for testing at isotropic as well as anisotropic stress states. This equipment has been used for test series with Yoldia clay as well as two types of sand to determine the maximum shear modulus, G_{max}. New methods for interpretations of the measurements from the tests have been studied intensively. Furthermore, during 1995 a comprehensive test program for Yoldia clay has been carried out in which Young's modulus, G_{max}, and the damping ratio have been determined by longitudinal resonant column tests fitted with bender elements.

In connection with the project a research period of 4 months has been completed at the Norwegian Geotechnical Institute in the beginning of 1995. During this period tests with bender elements and torsional resonant column tests were performed on two types of clay, two types of sand and one silt. The results from the research period are presented in [C1.2].

Plans for 1996

During the autumn of 1995 a new resonant column apparatus was installed at the Soil Mechanics Laboratory, Aalborg University for the purpose of performing torsional and longitudinal resonant column tests. Thus, it is possible to work with different strain levels when determining the shear modulus. The apparatus is being commissioned in the beginning of 1996 and the built-up of the large data base will continue during 1996. A model to describe the elastic properties of soils depending on stress levels, strain levels, soil characteristics such as void ratio, water content, plasticity index, overconsolidation ratio etc. will be worked out.

Participants

Lars Bødker, Ph.D. student, Department of Civil Engineering, Aalborg University.

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Publications

C1.1 L. Bødker : *G_{max} determined by bender element at anisotropic stress states*. Submitted to Nordisk Geoteknikermøde, NGM-96, Reykjavik, June 26-28, 1996.

C1.2 L. Bødker : *Resonant column calibration and testing at NGI.* Report No. 515139-1, Norwegian Geotechnical Institute, Oslo.

3.8 Project C2. Dynamic Response of Coarse Granular Materials To Wave Load.

Content and status

The project has been carried out as a combined theoretical - experimental project closely coordinated with the Marine Science and Technology II project: Monolithic Coastal Structures (EU - project). The main effort in 1995 was concentrated on preparing a general document describing design guidelines for the modelling of the structure - foundation interaction of monolithic caisson structures. [C2.13]. This document is the product of cooperation between several European Institutes. The foundation aspects of caisson breakwaters are described. Special attention is paid to dynamic response of the foundation to wave impacts, generation of pore pressures in the subsoil, degradation by repetitive loading and the interaction between all this aspects. The results of the theoretical work [C2.11] & [C2.12] are published in this general document.

The aim of the experimental part of the project has been to investigate the general mechanism guiding and controlling the response of the frictional soils subjected to static and dynamic loads [C2.3], [C2.8]. Drained as well as undrained static and dynamic triaxial tests have been performed on 5 different sand- and gravel materials. The tests have been performed with at least 3 relative densities for each material. The test material constitutes a unique data base which has formed the basis for Design Guidelines for Vertical Caisson Breakwaters. The results of the experimental work are published as data base in [C2.4],[C2.6], [C2.10].

The generalization of the Cam-Clay model started in 1994 has proceeded, and has now been formulated in a general invariant format. In addition the nonlinear elastic part of the model has ben extended to a more general form, also including nonlinear shear stiffness. A paper has been accepted for the IUTAM Symposium on Porous and Granular Materials, to be held in Cambridge in July 1996.

Plans for 1996

The plans for 1996 can be described in three parts

Part 1

The development of plasticity based models for granular materials commenced during the initial part of the program period will continue. A plasticity model will be developed and it will contain a numeric algorithm to describe triaxial stress-strain states in laboratory tests and engineering practice. The model requires only 3 rigidity parameters, namely the specific pore volume, the gradient of the "critical line", and a parameter to determine the dilatation in the state of failure. In spite of the few parameters, the model represents the qualitative behaviour of the material rather well including a stress-strain curve with top for over consolidated materials, a gradual transition from pressure to dilatation in a triaxial test as well as development of large stresses along the critical line before failure in an undrained triaxial test. The time dependent behaviour resulting from pore water movements will also be investigated. The data base concerning the behaviour of the material commenced during the initial part of the program period will be used to calibrate the model for different materials and to identify future necessary investigations.

Numerical algorithms will be developed for implementing the model into finite element programs. The key issue is the combination of nonlinear elasticity and the rather complicated mathematical form of the yield surface that makes an iterative plastic corrector procedure necessary
in order to remain on the yield surface during plastic loading. Properties of the more general nonassociated form of the theory will also be considered.

Part 2

In order to develop the model described in part 1 the existing data base must be supplemented with tests investigating the position of the characteristic state during a stress path which deviates fundamentally from the stress paths normally described in triaxial tests.

Part 3

So far this part of the project has been carried out as a combined theoretical-experimental project closely coordinated with the MAST II project: Monolithic Coastal Structures. The research will continue under MAST III with a limited grant. An investigation of the deformation- and strength properties of soil, including gravel, influenced by dynamic loads and pore pressure caused by waves are part of the research.
During 1996 and 1997 the majority of the research will still be within this area in order to provide a reliable determination of soil parameters to be used in dynamic calculations. Also, wave loads are going to be further investigated, including:

Probability distribution of wave load frequencies (particularly high-frequency wave loads).
The load distribution along a vertical caisson wall.
Damping from the involved hydrodynamic and geodynamic mass.
The deformation states in the caisson itself.

The investigation will include theoretical calculations as well as hydraulic and geotechnical model tests.

Participants

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Publications

C2.1 L.B. Ibsen: *The Stable State in Cyclic Loading*. Soil Dynamics & Earthquake Engineering. 6th International Conference. Bath, UK. June 1993, pp 241-258.

C2.2 H.F Burcharth & L.B. Ibsen: *Response of Rubble Foundation to Dynamic Loading.* Proceedings of International workshop on Wave Barriers in Deepwaters, Port and Harbour Research Institute Yokosuka, Japan Jan 10 - 14 1994, pp 402 - 417.

C2.3 L.B. Ibsen: *The Stable State in Cyclic Triaxial Testing on Sand. Elsevier,* Soil Dynamics and Earthquake Engineering 13, 1994, pp 63-72.

C2.4 L.B. Ibsen, L. Bødker: *Baskarp Sand No 15.* Data Report 9301, Soil Mechanics Laboratory,Aalborg University ,August 1994, Denmark.

C2.5 M. Borup & J. Hedegaard: *Characteristic State Modelling of Friction Materials.* M.Sc

Thesis, Aalborg University , January 1995, Denmark.

C2.6 M.Borup & J.Hedegaard. *Baskarp Sand No 15.* Data Report 9403, Soil Mechanics Laboratory, Aalborg University , January 1995, Denmark.

C2.7 A.Hansen & K.P.Jacobsen. *Fundamenters Stødbæreevne ved Plasticitetsteoriens øvreværdisætning.* M.Sc Thesis, Aalborg University, January 1995, Denmark.

C2.8 L.B. Ibsen: *The Static and Dynamic Strength of Sand.* XI ECSMFE ' 95 - European Conferance on Soil Mechanics and Foundation Engineering. Copenhagen, 28 May - 1 June, 1995, Volume 6 pp. 69 - 76.

C2.9 S. Krenk, M. Borup & J. Hedegaard: *Characteristic state model for sand.* XI ECSMFE '95 European Conference on Soil Mechanics and Foundation Engineering. Copenhagen, 28 May - 1 June, 1995. Volume 6 pp. 89 - 94.

C2.10 L.B. Ibsen & L. Bødker: *Blokhus sand.* Data Report 9501 part 1 & 2 ,Soil Mechanics Laboratory, Aalborg University,June 1995, Denmark .

C2.11 L.B. Ibsen & F.R Jacobsen:, *Soil Parameters.* Final proceedings MCS - Project MAST II, July 1995.

C2.12 C.S. Sørensen, L.B. Ibsen, A. Hansen and K.P. Jakobsen: *Bearing Capacity of Caisson Breakwaters on Rubble Mounds.* Final proceedings MCS - Project MAST II, July 1995.

C2.13 General Document: *Foundation design of caisson Breakwaters.* Monolithic (vertical) Coastal structures, Final proceedings MCS - Project MAST II, July 1995.

C2.14 S. Krenk, M. Borup and J. Hedegaard: *A triaxial characteristic state model for sand.* Proceedings of the Eleventh European Conference on Soil Mechanics and Foundation Engineering, Copenhagen, May 28 - June 1, 1995, pp. 89-94.

3.9 Project C3. Dynamics of Sports Stadiums

Content and status

A small 800 mm x 800 mm measuring platform of concrete and equipped with 3 force transducers has been produced. This platform is used to measure the vertical load from one person performing different movements such as jumping. The person has been equipped with an accelerometer at the waist to monitor his movements. However, it was difficult to get suitable results from the accelerometer because the electrical integration of the acceleration to displacement did not work very well. It was then decided to drop the accelerometer as transducer and instead use a new type displacement transducer. Some introductory measurements with this new type transducer have been carried out and the measurements are being analysed. Also the theoretical part of the project has been continued a bit. One of the participants in the project has changed job from Aalborg University to a consulting firm in Copenhagen and for the half of 1995 no work has been carried out in the project.

Plans for 1996

The teoretical part of the project will be continued and include the following. A simple impulse based load model for human motion will be developed. Finite element analysis will be used to make comparison with the experimentally determined eigenfrequencies. It is the aim to formulate a simple impulse based recommendation for loads on grandstands and similar structures as an alternative to the current use of static loads.

The experimental part of the project will be continued. The aim is first to determine the relations between the vertical human motion and the load impulse and then to determine the influence of eigenfrequencies and displacement amplitude of the underlying structure. Finally, to determine the influence of the number og people in relation to the eigenfrequency. The first aim will be fulfilled in the first part of 1996 with measurements in the laboratory using the small concrete load platform. After this the concrete platform will be mounted at different positions on a steel I-beam with movable supports, thus, allowing investigation of the influence of eigenfrequency and the displacement amplitude. The last measurements in the laboratory will include different numbers of people jumping on the I-beam. If possible, measurements will be performed in a real situation at a grandstand.

Publications

C3.1 Jeppe Jönsson and Lars Pilegaard Hansen: *Man induced actions on a small concrete platform.* To appear in 1996

Participants

Jeppe Jönsson, Research engineer, ES Consult A/S, Staktoften 20, 2950 Vedbæk.

Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University

3.10 Project C4. Dynamic Measurements on the Frejlev Mast

Content and status

The aim of this project is to make full-scale measurements on the Frejlev-mast which is a 200 meter high guyed steel mast located 10 km. from Aalborg. One of the goals will be to investigate the uncertainties of the modal parameters and mode shapes obtained by a practical application of time series models such as multi channel ARMA-models implementated in project B.1. Especially, problems concerning model reduction and separating closely-spaced modes will be investigated. Another goal is to estimate the cable forces from vibration measurements.

In June 1995 five cables of the Frejlev masts were instrumented in order to measure strains in the cables. However, it was found that the strain signals had a too low signal to noise ratio to be used for a further analysis. Since the strain signals could not be used the five cable became instrumentated with accelerometers. The accelerations in three directions were measured with 3 different types of excitation :

1. wind excitation
2. free-decays and
3 harmonic excitation by shaking the cables by the hand.

In order to establish the relationship between frequencies and cable forces different models of the dynamic response of a cable have been investigated.
The results of the measurements and the estimation of the cable forces will be presented in a report (Kirkegaard et al. [C4.1] and a paper (Kirkegaard et al. [C4.2]), respectively.

Plans for 1996

In 1996 it is planned to measure the response of one of the cables again, after accelerometers have been installed at the location where the cable is attached to the mast. These measurements will be used to investigate the influence of the motion of the cable support on the dynamic response of the cable.
In 1996 it is also planned to install accelerometers at the mast together with a cup-anemometer and wind vane in order to measure the response of the mast. These measurements will be analysed using techniques from the B.1. project.

Publications

C4.1 Kirkegaard, P.H & L.P. Hansen: *Vibration Measurements on the Frejlev Mast.* To appear in 1996.

C4.2 Kirkegaard, P.H & L.P. Hansen: *Estimation of Cable Forces of a Guyed Mast from Dynamic Measurements.* To appear in1996.

Participants

Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul Henning Kirkegaard, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

4. Final Remarks

The main conclusion is that the research programme meets all of its objectives. In all the Ph.D. projects the activity is very high and the results obtained in the projects have been published internationally in a large number of papers or presented at international conferences. The activity in the projects A2, C3 and C4 is not so high and only very small amounts of money are spent on these projects, see table 1 on page 3. It is the hope that there will be more activity in these projects in 1996 and 1997.

The Ph.D. students in the projects A1 and B3 have stopped at the end of 1995 and the activities in these projects will not be continued. On the other hand many new activities have been suggested in many of the other projects as described in chapter 3.

The relations to Danish and foreign institutes and consulting engineering companies have been continued and some new established.

It is our hope that the programme will provide more knowledge and data to design dynamically sensitive structures in a more reliable and economic way.

Aalborg, March 29, 1996.

Lars Pilegaard Hansen

Lars Pilegaard Hansen

APPENDIX J

Procedure for the programme (In Danish)

INSTITUTTET FOR BYGNINGSTEKNIK
AALBORG UNIVERSITETSCENTER

27.1.1994

Rammeprogram for Konstruktioners Dynamiske Forhold

Forretningsorden

Rammeprogram for Konstruktioners Dynamiske Forhold gennemføres efter kontrakt med Statens Teknisk-Videnskabelige Forskningsråd med deltagelse af følgende institutter/forskergrupper:

Institut for Bygningsteknik, AUC
Institut for Vand, Jord og Miljøteknik, AUC
Afdelingen for Bærende Konstruktioner, DTH

Aftaleperioden er 1. januar 1993 - 31. december 1997. Ændringer i rammeprogrammets organisation kan ske efter forskningsrådets godkendelse.

Programmets formål

Rammeprogrammets formål er at drive forskning, forskeruddannelse og formidling af resultater med relation til konstruktioners dynamiske opførsel. Der arbejdes i rammeprogrammet med dynamisk last og konstruktionsrespons, herunder geotekniske forhold, ved brug af analytiske og eksperimentelle metoder. Programmet omfatter også beskrivelse og modellering af materialers opførsel under vekslende last.

Programmets organisation

Programmet ledes af en programleder og en programkomiteé, udpeget af forskningrådet.

Programlederen er fagligt og administrativt ansvarlig over for forskningsrådet for programmets virksomhed, herunder ansættelse af personale.

Programkomiteé består ud over programlederen af yderligere 5 medlemmer: en repræsentant for forskergruppen ved hvert af de medvirkende institutter samt 2 eksterne medlemmer. Programkomiteén vælger en formand blandt de eksterne medlemmer. Formanden leder komiteéns møder. Programlederen udpeger en medarbejder som sekretær for komiteéns møder. Programlederen kan invitere udvalgte medarbejdere til at deltage i komiteéns møder.

Det er programkomiteéns opgave at følge med i programmets virksomhed, samt at vurdere denne og tage initiativ til justeringer eller ændringer, hvis dette skønnes nødvendigt. Programkomiteén mødes ca. 4 gange om året. Det tilstræbes, at der i forbindelse med disse møder afholdes et fagligt arrangement - foredrag, laboratoriebesøg eller lignende - for alle projektets deltagere. Programkomiteén tager initiativ til etablering af forbindelser mellem rammeprogrammet og beslægtede faglige miljøer. En gang om året inviteres disse, samt øvrige interesserede, til et fagligt heldagsmøde, vedrørende konstruktioners dynamiske forhold.

Der afholdes månedlige projektmøder med alle projektdeltagere med diskussion af status, planer samt gensidig orientering om faglige fremskridt. Programledelsen varetager den daglige ledelse, herunder budgetopfølgning, med bistand af projektets sekretær.

Administration

Programmet har en selvstændig økonomi, der bestyres af programlederen med assistance af projektets sekretær. Aalborg Universitetscenter varetager de administrative forhold med hensyn til personale med videre.

APPENDIX K

Evaluation from the programme committee

Evaluation of the research programme DYNAMICS OF STRUCTURES

The purpose of the programme is to conduct research, provide research education and to obtain results relating to dynamic loads and response of structures and foundations. Modelling of materials under varying loads is also part of the research programme. Both analytical and experimental methods are developed and used in the research.

The research programme started in 1993 and it was completed in the end of 1997. The research programme is divided into three main topics consisting of basic theory, experimental techniques and selected dynamic problems. The research programme consists of 10 research projects totally.

Damage detection in structures has been a main issue in two of the research projects. Dynamic loads, such as wind load, wave load and loads induced by spectator motions are also analysed in the research projects. The results obtained have been used to calibrate wind load and spectator motion specifications included in the new Danish code expected to be published in June 1998. Foundation behaviour is an important design aspect of dynamically loaded structures and two of the projects concentrate on soil behaviour and soil parameters under dynamic loading. One utilisation of the results of these projects is input to the formulation of a document on : "Design Guidelines for Vertical Caisson Breakwaters" in an EU research programme under MAST II.

There is a suitable interrelation between the methods used and results obtained in the different projects carried out.

The seminars arranged in September 1994 and November 1996 gave a good mixture of presentations describing the results obtained in the research programme and presentations by consulting engineers showing the present methods used in practical design.

Main conclusion:

The main conclusion is that the research programme has met all of its objectives. The research standard is very high and the results obtained in the projects have been published internationally in a large number of papers, some of those presented at international conferences. The programme has increased the competence of Aalborg University in the area of dynamics of structures both through increased knowledge and new advanced equipment.

Good external relations to other Danish and foreign institutes and consulting engineering companies, as well as to other research programmes, have been established and continued. With the aquired competence Aalborg University will be an interesting contact for Danish and foreign institutes and companies in the field of structural dynamics also in the future.

The results obtained in the research programme will be useful for the industry and consulting engineers designing dynamically sensitive structures on land, offshore and along the coast. The trend towards lighter and more flexible structures makes the results obtained highly relevant for present and for future structural designs. The programme will provide knowledge and data to design dynamically sensitive structures more reliable and more economically.

Svend Ole Hansen and Knut H. Andersen, programme committee, 25 March 1998

APPENDIX L

Evaluation of the programme 1995

2.2.6 Konstruktioners Dynamiske Forhold.

Dynamics of Structure.

Evaluation report by Professor David Muir Wood, Department of Civil Engineering, The University of Glasgow, Scotland.

Introduction.

The research programme on Dynamics of Structures is a loose collection of research projects concerned with civil engineering dynamics largely based in the Department of Building Technology and Structural Engineering at Aalborg University, with some projects being pursued in the Department of Civil Engineering at Aalborg University and in the Department of Structural Engineering at the Technical University of Denmark. The programme was started in 1993 and is intended to continue until 1997 or 1998. Brief reports have been submitted describing the initial research that has been performed during 1993 and 1994 together with an outline of the research activities planned for 1995. - In addition a brief evaluation report produced by the Programme Committee (Svend O. Hansen and Knut Andersen) has also been provided.

Disclaimer.

I have a general training in and awareness of most aspects of civil engineering. However, my research activity has centred on geotechnical engineering so that my comments on other areas of the research programme may be regarded as less informed and less reliable.

A. Basic theory.

A1. Mode shape and reduced base techniques.

This project is concerned with the development of efficient numerical procedures for identifying vibration modes for structures with a large number of degrees of freedom in the presence of damping. This work appears to be essential to underpin several of the other projects concerned with structural response.

A2. Wind loads on structures.

The original title of the project was "Self-induced oscillations".

The project is now specifically concerned with collection of data for wind loading on structures in Denmark. The dynamic wind loading is complex to describe because of the interaction of structure and shed vortices. The project is essentially phenomenological and does not appear to be combined with any theoretical or analytical studies of the generation of wind loads on structures.

A3. Dynamic response of structures with stochastic properties and excitation.

In appears that this work is concerned both with the forward problem of predicting the response of structures, whose properties are subject to stochastic variation, under loads which also vary randomly, and also with the reverse problem of attempting to deduce from the observed dynamic response - or change in dynamic response - the location in the structure at which degradation of material may have occurred. (The report uses the term "localization" several times but localization has to me a particular meaning of concentration of deformation in a narrow region, typically occurring in a strain softening material, and from the context I suspect that "location" may be intended here).

This notion of pin-pointing of location of damage from observed dynamic response is being studied by many researchers around the world. It may well be more tractable for certain classes of structure - cable-stayed masts are likely to be particularly suitable. It will be interesting to see whether the procedures can be operated efficiently for reinforced concrete structures, which are more continuous and less discrete.

B. Experimental techniques.

B1. Damage detection in structures under random loading.

This project appears to overlap somewhat in its aims with project A3 in that it too is concerned with algorithms for location of damage from observed dynamic response. It is perhaps surprising that there is no overlap in personnel between this project and project A3.

Links with industry have already been formed in order to gather data on changing dynamic response of offshore structures. Data have been gathered from laboratory experiments on a steel lattice mast.

The changing dynamic response of offshore structures will very likely be the result of changing foundation characteristics. I wonder how sensitive the procedures are to the details of the extremely non-linear foundation response. It would be reassuring to see some geotechnical involvement in this project.

B2. Modal analyses based on random decrement signatures.

This project started only in September 1994 and at the time of the report only a survey of literature relating to the applications of Random Decrement techniques had been completed. It is intended to study the theoretical background to Random Decrement techniques more closely.

This is not an area with which I have any familiarity.

B3. Fatigue and crack propagation.

Series of tests on metal and concrete specimens have been completed to study the crack propagation under fatigue loading. The existence of a link between crack propagation and fatigue stress intensity factor seems to be entirely predictable and has formed the basis of fatigue analysis for many years. No information is given concerning the newly developed crack propagation formula from which its novelty might be assessed.

Specimens of concrete have been tested under triaxial conditions presumably in order to collect basic data on stress:strain characteristics to use as input to analysis of notched specimens. The stress conditions around a notch will be quite complex and the researchers will no doubt wish to link their own data with data obtained elsewhere for the behaviour of concrete under more general stress conditions (multiaxial stress states with three different principal stresses, tests with controlled rotation of principal axes).

C. Selected dynamic problems.

The original title for this group of projects was "Selected structural problems".

C1. Behaviour of soil subjected to dynamic loads.

The original title for this project was "Behaviour of structures subjected to dynamic ground motion". The emphasis has been shifted to the response of the ground on its own.

Young's modulus, shear modulus and damping ratio are being determined under dynamic loading for several different soils with different void ratios, and under different stress states and strain states. Initial experiments have been performed on a small shaking table using bender elements to determine shear modulus. It is intended to develop a resonant column apparatus capable of applying dynamic axial loading and torque to that more control can be exercised over strain levels. The data are being sought in relation to problems of high frequency, very small amplitude loading such as machine foundations and traffic loading. These data will not be directly relevant to assessment of offshore foundation stiffness under cyclic or dynamic loads. I am not sure of the typical dominant frequency of wind loading on structures and am therefore not sure whether the data will be relevant to interpretation of the response of the foundations of structures (such as guyed masts) subjected to wind loading.

C2. Dynamic response of coarse granular materials to wave load.

The very specific objectives of this project relate to a MAST project on breakwaters. It is unclear from the report whether the breakwaters are being analysed under dynamic loading, or whether the material properties to be used in static analysis are merely to be obtained from dynamic laboratory tests. It is stated that failure modes have been identified for monotonic loading. It is to be hoped that when the constitutive model for the granular materials has been completely formulated it will be possible to run dynamic as well as static finite element analysis.

C3. Dynamics of sports stadia.

Sports stadia provide an excellent opportunity for the observation and analysis of the effects of random dynamic loading on complex structures. The assembly of likely patterns of stochastic loading from the individual impulses of which humans are capable will require sociological input as well as technical analysis.

C4. Dynamic measurements on the Frejlev mast.

This project is additional to those on the original list but projects such as this, concerning specific dynamic problems in cooperation with external partners, are mentioned at the end of the original project description.

Guyed mast structures should in principle be rather straightforward to analyse in a deterministic manner and there are good possibilities for validating some of the theoretical procedures that are being developed in other projects, particularly for response to random loads, effects of wind loading, and consequences of limited damage. In this project too I suspect that some geotechnical involvement could be useful in the assessment of foundation stiffness and the potential for change of foundation stiffness with loading cycles.

Conclusion.

The Tables show the distribution of involvement of academic staff in the several projects, the allocation of research students, the links with external organizations - mostly universities or research organizations, from the limited information that I can glean - and the approximate distribution of publications. Some of the projects have been remarkably prolific in generating conference papers and internal reports given the short time that the Frame Programme has been running.

I am not entirely familiar with the ways in which university research is carried out in Denmark and my curiosity as to who is performing the work in projects that appear to have no research students (A2, C3) reflects this. Without knowing the level of funding for the programme I am not able to comment on whether the level of research training provided is appropriate. It appears that about 6 doctoral students are being supported, and that a number of MSc students are being involved in project C2.

Most of the projects have some links with external organizations. It may well be that other links exist that have not been mentioned in this report. I am not really able to assess how valuable all the stated links will be: for example, project B1 seems to have a large number of contacts in place. There is certainly advantage in obtaining collaborative access to high quality dynamic response data from external sources where they are available, and also advantage in tapping the research experience that has been gained elsewhere. Inevitably in some of the project areas the topics being studied are ones that are of concern in many other institutions.

Although I am not completely aware of the arrangements for Frame Programmes, I have some concern at the apparent absence of overall coordination and focus for these projects. For example, I would like to feel that the theoretical work was not being conducted in isolation from the experimental studies, that the theoretical studies of the effects of damage on dynamic response of structures were linked with the corresponding experimental studies of damage and crack propagation (to give the assumed damage mechanisms some validity), and that the geotechnical work was directly linked with the projects under consideration. The obvious danger is that, with projects proceeding without reference to each other, the overall Programme will end and rather vital gaps will be found to remain. I do not think that it is too early in the Programme for a brain-storming session to be held at which all those involved in all the projects meet together to review progress and identify lacunae. Perhaps such meetings have indeed taken place, that is not apparent from the material provided.

Let me not end on a negative note. Overall this brief preliminary report appears to be describing research of high quality and certainly of a level and standard comparable with research of which I am aware in the UK and in other countries. The research contained within this Frame Programme appears to be progressing well and to be of a quality which will bring credit to the Danish Technical Research Council.

Tabel 1: Collected statistics.

	Project									
	A1	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**	**C4**
Academic staff	1	2	1	3	2	2	1	3	2	3
Aalborg - Building										
Brincker				*	*					*
L. P. Hansen				*		*			*	*
Jønsson									*	
Kirkegaard				*	*					*
Krenk	*	*						*		
S. Nielsen		*	*							
Aalborg - Civil										
Burcharth								*		
Ibsen							*	*		
DTU										
M. P. Nielsen						*				
Research students										
Aalborg - Building										
Ph.D.	1		1	0,5	1					0,5
Aalborg - Civil										
Ph.D.							1			
M.Sc.								2		
DTU										
Ph.D.						1				
Publications										
Reports	6	1	7	3		1		3		
Conferences	5	1	1	9	1			3	1	
Journals (in press)	(2)		(2)	1						
Collaborations	2	2	1	7	1	?	1	1	1	1

Tabel 2: Collaborations and external links.

A1	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**	**C4**
Lund Delft	Wien industry	Princeton	Poland Greece Ispra Torino Venezuela* Norway* Old Dominion	Old Dominion	†	Oslo*	Delft	Göteborg	industry

* industry
† links with several unspecified countries

Evaluation report by Professor Bengt Åkesson, Division of Solid Mechanics, Chalmers University of Technology, Göteborg, Sweden.

Document: "Dynamics of Structures - Progress Report 1993-1994" from Department of Building Technology and Structural Engineering at Aalborg University (18 pages signed 27. February 1995 by Steen Krenk).

The Programme.

The programme runs from 1993 until the end of 1997 and is a joint undertaking by the above Department at Aalborg University and the Department of Structural Engineering at The Danish Technical University. Six Ph.D. students are engaged. The detailed contents of the contracted programme are given elsewhere.

A. Basic Theory.

A remarkably ambitious activity is reported on "A.1 Mode Shape and Reduced Base Techniques" (Steen Krenk and coworkers), "A.2 Wind Loads on Structures" (Svend Ole Hansen, Steen Krenk and Søren R. K. Nielsen) and "A.3 Dynamic Response of Structures with Stochastic Properties and Excitation" (Søren R. K. Nielsen and coworkers). The applied and developed analytical and numerical techniques are up-to-date. Results have been presented at conferences and in journals of a high scientific reputation.

B. Experimental Techniques.

The same high level of activity seems to prevail for "B.1 Damage Detection in Structures under Random Loading", "B.2 Modal Analysis Based on Random Decrement Signatures" and "B.3 Fatigue and Crack Propagation" (Rune Brincker, Poul Henning Kirkegaard, Mogens Peter Nielsen and coworkers). Scientific and industrial expertise from abroad helps to form a solid basis for the research. The publication activity is noteworthy.

C. Selected Dynamic Problems.

The subprogrammes are "C.1 Behaviour of Soil Subjected to Dynamic Loads", "C.2 Dynamic Response of Coarse Granular Materials to Wave Load", "C.3 Dynamics of Sports Stadiums" and "C.4 Dynamic Measurements on the Frejlev Mast". A somewhat less intense activity is reported here, one reason being stated on the first page of Steen Krenk's Progress Report. The problems under investigation are broad and of a more applied nature than those under A and B.

Conclusions.

Being myself fairly well acquainted with fundamental and applied research in the structural dynamics area of civil engineering. I have no problem in appreciating the ongoing research activity, the results achieved so far, and the programme plans for the future. Professor Steen

Krenk and all his groups at AUC should be commended for their work (the contribution from DTU seems to be rather marginal).

By international standards, the quality of the research is high. The involvement of Ph.D. students favours the commercial dissemination of results (people in industry most often do not read scientific papers but do hire scientifically educated Ph.D.'s. The national and international cooperation is excellent. The presentation and discussion of the results of the programme at an annual workshop is a good idea (the first one took place in Aalborg in September 1994).

Finally, the present Progress Report has an attractive layout and a concise mode of expressing facts. It has been a pleasure to read it.